CURRENT DIFFERENCING TRANSCONDUCTANCE AMPLIFIERS AND THEIR APPLICATIONS

Project Report submitted in partial fulfillment of the requirement
for the degree of
Bachelor of Technology
in

Electronics and Communication Engineering

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Certificate

This is to certify that the project report entitled "**Current Differencing Transconductance Amplifiers and Their Applications**", submitted by Shivam Rastogi (061123), Shweta Tiwari (061125) and Anshika Chaudhary (061604) in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

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Certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma

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1. Current Differencing Transconductance Amplifier (CDTA)
2. Operational Amplifier (Op-Amp)
3. Current mode (CM)
4. Direct current (DC)
5. Common-mode rejection ratio (CMRR)
6. IC Integrated circuit
7. Power supply rejection ratio (PSRR)
8. Operational Transconductance Amplifier (OTA)
9. Voltage controlled current source (VCCS)
10. High-pass filter (HPF)
11. Low-pass filter (LPF)
12. Band-pass filter (BPF)
13. Current Controlled Current Differencing Transconductance Amplifiers (CCCDTA).

ABSTRACT

We have hitherto been using voltage mode elements like op-amps for implementation of various electronic circuits. These elements are used widely owing to their small sizes and good performance.

Yet nowadays the demand for portable battery powered equipment is increasing. This issue can't be solved with voltage mode elements as the voltage supply if reduced will cause problems with realizing circuits. Instead, current mode (CM) elements can be used for the same circuits and these issues can then be addressed.

In this project, we have used Current Differencing Transconductance Amplifier (CDTA) as the active element operating in current-mode and applied it on various circuits. We have realized the circuits for comparator, second order high pass, second order low pass, second order band pass filters and Quadrature oscillators and analyzed using results how the performance of current mode elements is better than the voltage mode ones.

CHAPTER 1

INTRODUCTION

1.1 PROJECT MOTIVATION

Operational Amplifiers (Op-amps) are basically Analog Integrated circuits and have been in used extensively because of their small size and weight, better cost and performance and quick designing. But there are certain issues with these ICs:

- They cannot be used in High Voltage Applications.
- The parasitic capacitances cause problems of power consumption (charging and discharging of capacitances).
- Speed (regulation of capacitances)

Low-voltage signal processing is one of the main goals of today's analog designers because of the trend of low supply voltages in technology and the need for low power consumption in portable devices. On the other hand, analog signal processing in very low supply voltages can be best accomplished in the current-mode.

The demand for electronic circuits with extremely low supply voltages and power consumption belongs to important and long-term trends which affect the development of microelectronic technologies. In many applications, additional requirements appear, particularly the extreme speed or the accuracy of signal processing. In contrast to the conventional voltage mode, which utilizes electric voltages, the current-mode circuits can exhibit under certain conditions – among other things – higher bandwidth and better signal linearity.

Since they are designed for lower voltage swings, smaller supply voltages can be used. The current-mode approach to signal processing has often been claimed to provide one or more of the following advantages: higher frequency range of operation, lower power consumption, higher slew rates, improved linearity, and better accuracy. [2] The initial set of active elements for analog signal processing is currently evolving in two directions. Comprehensiveness and the variety of the circuit principles used today. The reason consists in the variety of specific requirements, imposed on the analog subsystems working in various operating modes and under their interaction with digital circuits: high dynamic range, noise immunity, low supply voltage and power consumption, high linearity and high bandwidth, low nonlinear distortion, specific impedance levels, etc.

The contemporary active elements such as operational transconductance amplifier, second generation current conveyor, current feedback amplifier, etc can be used but these active devices have either high input impedance and high output impedance or high input impedance and low output impedance. The requirement for CM circuits is low input (ideally zero) and high output (ideally infinite).The desire of realizing circuits with such an element which would solve all these issued inspired us to take up this project.

1.2 PROJECT OBJECTIVE

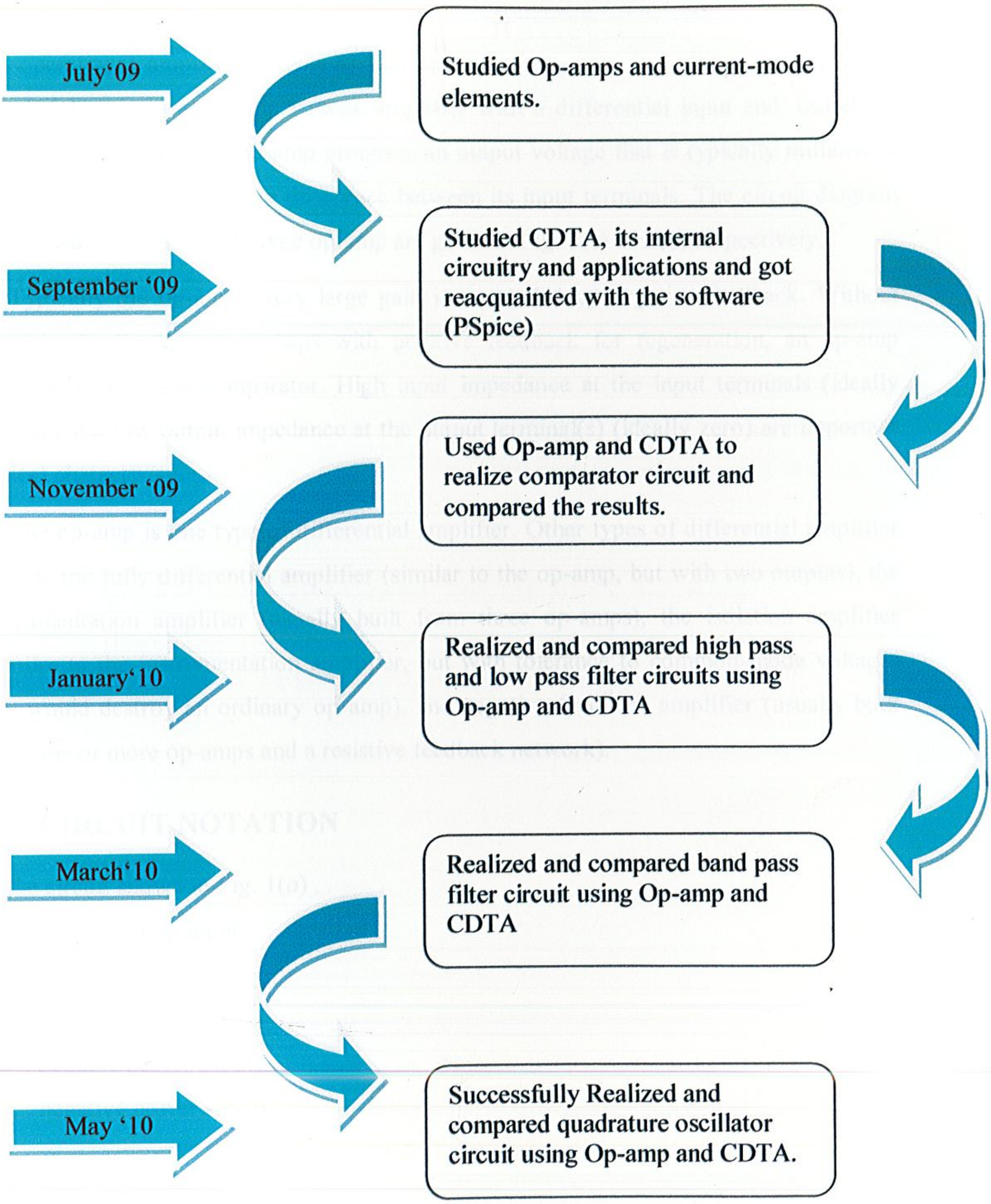
To design and use a current mode element which has low input impedance and high output impedance , realize various circuits using this element and compare its results with the conventional op-amp.

The CDTA is a highly desirable active device for the implementation of signal processing in current mode as it has low input and high output impedances. In this project, we have aimed to use a single CDTA and bare minimum number of passive components to implement various circuits. [3] The output current is available at high impedance thereby lending cascadibility to the circuit.

This element consists of a unity-gain current source controlled by the difference of the input currents and a multi-output transconductance amplifier providing electronic tenability through its transconductance gain. The use of CDTA as active component simplifies the implementation thereby providing the circuits with lesser number of passive components as opposed to its counterparts leading to compact structures in some applications.

1.3 PROJECT PROGRESS

Here we have summarized the complete life cycle of our project:



CHAPTER-2

OPERATIONAL AMPLIFIER

An operational amplifier, which is often called an op-amp, is a direct current (DC)-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. An op-amp produces an output voltage that is typically millions of times larger than the voltage difference between its input terminals. The circuit diagram and typical pin-out for 741 type op-amp are given in Fig. 1(a) and (b) respectively.

Typically the op-amp's very large gain is controlled by negative feedback. Without negative feedback, and perhaps with positive feedback for regeneration, an op-amp essentially acts as a comparator. High input impedance at the input terminals (ideally infinite) and low output impedance at the output terminal(s) (ideally zero) are important typical characteristics.

The op-amp is one type of differential amplifier. Other types of differential amplifier include the fully differential amplifier (similar to the op-amp, but with two outputs), the instrumentation amplifier (usually built from three op-amps), the isolation amplifier (similar to the instrumentation amplifier, but with tolerance to common-mode voltages that would destroy an ordinary op-amp), and negative feedback amplifier (usually built from one or more op-amps and a resistive feedback network).

2.1 CIRCUIT NOTATION

In the circuit shown in Fig. $1(a)$,

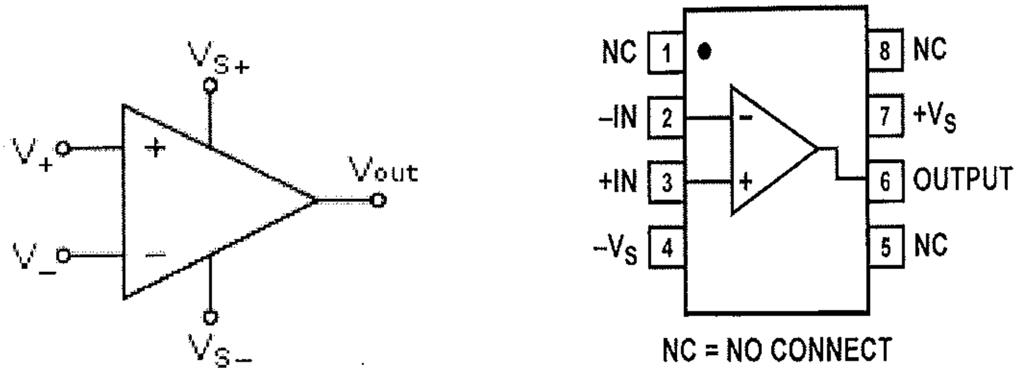
V_+ : non-inverting input

V_- : inverting input

V_{out} : output

V_{s+} : positive power supply

V_{s-} : negative power supply



(*a*) (*b*)

Fig. 1(*a*): Circuit diagram symbol for an op-amp, (*b*) Pin out for 741-type operational amplifier.

The power supply pins (V_{s+} and V_{s-}) can be labeled in different ways. Despite different labeling, the function remains the same to provide additional power for amplification of signal. Often these pins are left out of the diagram for clarity, and the power configuration is described or assumed from the circuit.

2.2 INTERNAL CIRCUITRY OF 741 TYPE OP-AMP

Though designs vary between products and manufacturers, all op-amps have basically the same internal structure, as shown in Fig. 2, which consists of three stages:

- Differential amplifier – provides low noise amplification, high input impedance, usually a differential output.
- Voltage amplifier–provides high voltage gain, a single-pole frequency roll-off usually single-ended output.
- Output amplifier – provides high current driving capability, low output impedance, current limiting and short circuit protection circuitry.

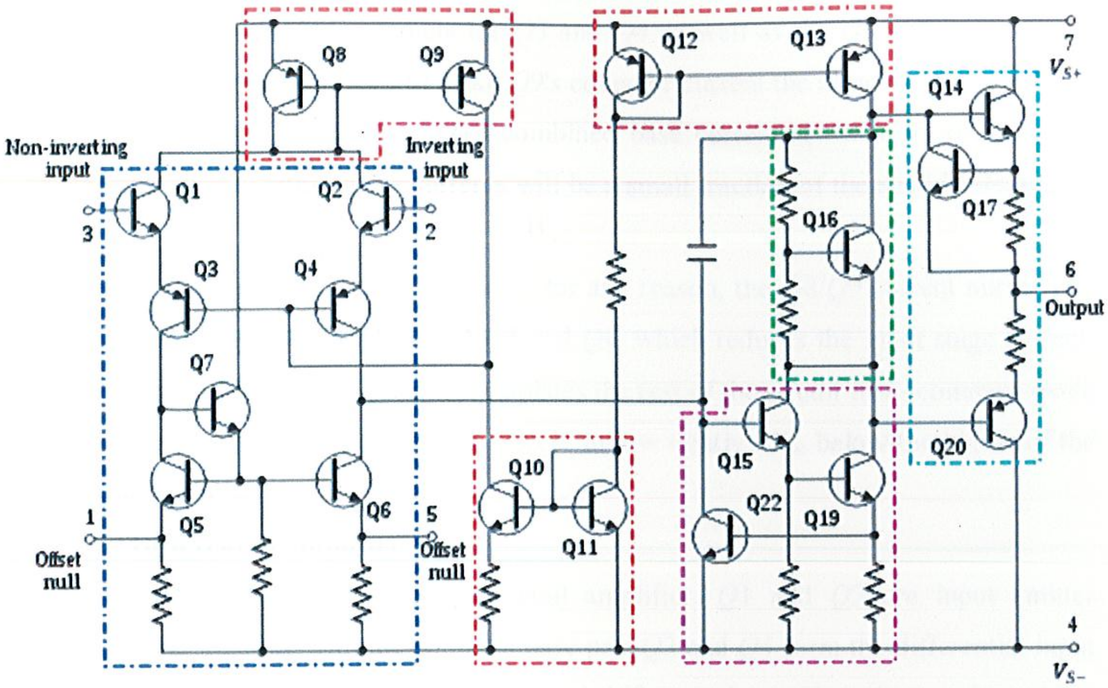


Fig. 2: A component level diagram of the common 741 op-amp. Dotted lines outline: current mirrors (red); differential amplifier (blue); class A gain stage (magenta); voltage level shifter (green); output stage (cyan).

2.2.1 INPUT STAGE

2.2.1.1 Constant-current stabilization system

The input stage DC conditions are stabilized by a high-gain negative feedback system whose main parts are the two current mirrors on the left of the figure, outlined in red. The main purpose of this negative feedback system—to supply the differential input stage with a stable constant current—is realized as follows:

The current through the 39 kΩ resistor acts as a current reference for the other bias currents used in the chip. The voltage across the resistor is equal to the voltage across the supply rails (V_{s+} - V_{s-}) minus two transistor diode drops (i.e., from Q11 and Q12), and so the current has value

$$I_{ref} = V_{s+} - V_{s-} - 2V_{be} \ / \ 39k\Omega$$

The Widlar current mirror built by Q10, Q11, and the 5 kΩ resistor produces a very small fraction of I_{ref} at the Q10 collector. This small constant current through Q10's collector supplies the base currents for *Q*3 and *Q*4 as well as the *Q*9 collector current. The *Q*8/*Q*9 current mirror tries to make *Q*9's collector current the same as the *Q*3 and *Q*4 collector currents. Thus *Q*3 and *Q*4's combined base currents (which are of the same order as the overall chip's input currents will be a small fraction of the already small *Q*10 current.

So, if the input stage current increases for any reason, the *Q*8/*Q*9 current mirror will draw current away from the bases of *Q*3 and *Q*4, which reduces the input stage current, and vice versa. The feedback loop also isolates the rest of the circuit from common-mode signals by making the base voltage of *Q*3/*Q*4 follow tightly $2V_{\text{be}}$ below the higher of the two input voltages.

2.2.1.2 Differential amplifier

The blue outlined section is a differential amplifier. *Q*1 and *Q*2 are input emitter followers and together with the common base pair *Q*3 and *Q*4 form the differential input stage. In addition, *Q*3 and *Q*4 also act as level shifters and provide voltage gain to drive the class A amplifier. They also help to increase the reverse V_{be} rating on the input transistors (the emitter-base junctions of the NPN transistors *Q*1 and *Q*2 break down at around 7 V but the PNP transistors *Q*3 and *Q*4 have breakdown voltages around 50 V).

The differential amplifier formed by *Q*1–*Q*4 drives a current mirror active load formed by transistors *Q*5–*Q*7 (actually, *Q*6 is the very active load). *Q*7 increases the accuracy of the current mirror by decreasing the amount of signal current required from *Q*3 to drive the bases of *Q*5 and *Q*6. This configuration provides differential to single ended conversion as follows:

The signal current of *Q*3 is the input to the current mirror while the output of the mirror (the collector of *Q*6) is connected to the collector of *Q*4. Here, the signal currents of *Q*3 and *Q*4 are summed. For differential input signals, the signal currents of *Q*3 and *Q*4 are equal and opposite. Thus, the sum is twice the individual signal currents. This completes the differential to single ended conversion.

The open circuit signal voltage appearing at this point is given by the product of the summed signal currents and the paralleled collector resistances of *Q*4 and *Q*6. Since the collectors of *Q*4 and *Q*6 appear as high resistances to the signal current, the open circuit voltage gain of this stage is very high.

It should be noted that the base current at the inputs is not zero and the effective (differential) input impedance of a 741 is about 2 MΩ. The "offset null" pins may be used to place external resistors in parallel with the two 1 kΩ resistors (typically in the form of the two ends of a potentiometer) to adjust the balancing of the $Q5/Q6$ current mirror and thus indirectly control the output of the op-amp when zero signal is applied between the inputs.

2.2.1.3 Class A gain stage

The section outlined in magenta is the class A gain stage. The top-right current mirror $Q12/Q13$ supplies this stage by a constant current load, via the collector of $Q13$ that is largely independent of the output voltage. The stage consists of two NPN transistors in a Darlington configuration and uses the output side of a current mirror as its collector load to achieve high gain. The 30 pF capacitor provides frequency selective negative feedback around the class A gain stage as a means of frequency compensation to stabilise the amplifier in feedback configurations. This technique is called Miller compensation and functions in a similar manner to an op-amp integrator circuit. It is also known as 'dominant pole compensation' because it introduces a dominant pole (one which masks the effects of other poles) into the open loop frequency response. This pole can be as low as 10 Hz in a 741 amplifier and it introduces a -3 dB loss into the open loop response at this frequency. This internal compensation is provided to achieve unconditional stability of the amplifier in negative feedback configurations where the feedback network is non-reactive and the closed loop gain is unity or higher. Hence, the use of the operational amplifier is simplified because no external compensation is required for unity gain stability; amplifiers without this internal compensation may require external compensation or closed loop gains significantly higher than unity.

2.2.1.4 Output bias circuitry

The green outlined section (based on $Q16$) is a voltage level shifter or rubber diode (i.e., a V_{BE} multiplier); a type of voltage source. In the circuit as shown, $Q16$ provides a constant voltage drop between its collector and emitter regardless of the current through the circuit. If the base current to the transistor is assumed to be zero, and the voltage between base and emitter (and across the 7.5 kΩ resistor) is 0.625 V (a typical value for a BJT in the active region), then the current through the 4.5 kΩ resistor will be the same as that through the 7.5 kΩ, and will produce a voltage of 0.375 V across it. This keeps the voltage across the transistor, and the two resistors at 0.625 + 0.375 = 1 V. This serves to bias the two output transistors slightly into conduction reducing crossover distortion. In some discrete component amplifiers this function is achieved with (usually two) silicon diodes.

2.2.2 OUTPUT STAGE

The output stage (outlined in cyan) is a Class AB push-pull emitter follower (*Q*14, *Q*20) amplifier with the bias set by the V_{be} multiplier voltage source *Q*16 and its base resistors. This stage is effectively driven by the collectors of *Q*13 and *Q*19. Variations in the bias with temperature, or between parts with the same type number, are common so crossover distortion and quiescent current may be subject to significant variation. The output range of the amplifier is about one volt less than the supply voltage, owing in part to V_{be} of the output transistors *Q*14 and *Q*20.

The 25 Ω resistor in the output stage acts as a current sense to provide the output current-limiting function which limits the current in the emitter follower *Q*14 to about 25 mA for the 741. Current limiting for the negative output is done by sensing the voltage across *Q*19's emitter resistor and using this to reduce the drive into *Q*15's base. Later versions of this amplifier schematic may show a slightly different method of output current limiting. The output resistance is not zero, as it would be in an ideal op-amp, but with negative feedback it approaches zero at low frequencies.

2.3 OPERATION

The operation of op-amps can be explained, depending on the whether the feedback is given or not as follows:

2.3.1 OP-AMP WITHOUT FEEDBACK

Fig. 3 shows the structure of an op-amp without feedback. The amplifier's differential inputs consist of a V_+ input and a V_- input, and ideally the op-amp amplifies only the difference in voltage between the two, which is called the differential input voltage.

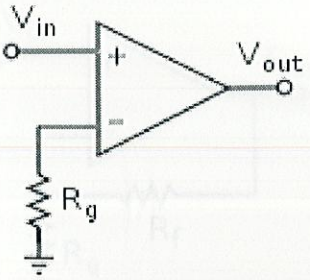


Fig. 3: Op-amp with resistance R_g

The output voltage of the op-amp is given by the equation,

$$V_{out} = (V_+ - V_-)\, G_{openloop}$$

where V_+ is the voltage at the non-inverting terminal, V_- is the voltage at the inverting terminal and $G_{open\text{-}loop}$ is the open-loop gain of the amplifier. (The term open-loop refers to the absence of a feedback loop from the output to the input).

With no negative feedback, the op-amp acts as a switch or comparator. The inverting input is held at ground (0 V) by the resistor, so if the V_{in} applied to the non-inverting input is positive, the output will be maximum positive, and if V_{in} is negative, the output will be maximum negative. Since there is no feedback from the output to either input, this is an open loop circuit. The circuit's gain is just the $G_{open\text{-}loop}$ of the op-amp. Positive feedback may be used to introduce hysteresis or oscillation.

2.3.2 OP-AMP WITH FEEDBACK

Adding negative feedback via R_f reduces the gain. Fig. 4 shows such an op-amp. Equilibrium will be established when V_{out} is just sufficient to reach around and pull the inverting input to the same voltage as V_{in}. As a simple example, if $V_{in} = 1V$ and $R_f = R_g$, V_{out} will be 2V, the amount required to keep V_- at 1V. Because of the feedback provided by R_f, this is a closed loop circuit. Its over-all gain V_{out} / V_{in} is called the closed-loop gain $G_{closed\text{-}loop}$. Because the feedback is negative, in this case $G_{closed\text{-}loop}$ is less than the $G_{open\text{-}loop}$ of the op-amp.

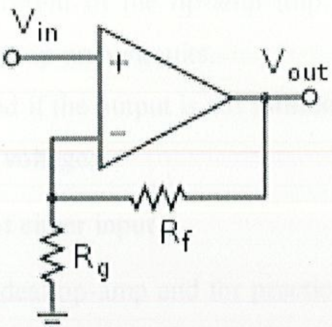


Fig. 4: Op-amp with resistance R_g and R_f

The magnitude of $G_{\text{open-loop}}$ is typically very large—seldom less than a million—and therefore even a quite small difference between V_+ and V_- (a few microvolts or less) will result in amplifier saturation, where the output voltage goes to either the extreme maximum or minimum end of its range, which is set approximately by the power supply voltages. Finley's law states that "When the inverting and non-inverting inputs of an op-amp are not equal, its output is in saturation."

Additionally, the precise magnitude of $G_{\text{open-loop}}$ is not well controlled by the manufacturing process, and so it is impractical to use an operational amplifier as a stand-alone differential amplifier. If linear operation is desired, negative feedback must be used, usually achieved by applying a portion of the output voltage to the inverting input. The feedback enables the output of the amplifier to keep the inputs at or near the same voltage so that saturation does not occur.

Another benefit is that if much negative feedback is used, the circuit's overall gain and other parameters become determined more by the feedback network than by the op-amp itself. If the feedback network is made of components with relatively constant, predictable, values such as resistors, capacitors and inductors, the unpredictability and inconstancy of the op-amp's parameters (typical of semiconductor devices) do not seriously affect the circuit's performance.

2.4 GOLDEN RULES OF OP-AMP NEGATIVE FEEDBACK

Returning to a consideration of linear (negative feedback) operation, the high open-loop gain and low input leakage current of the op-amp imply two "golden rules" that are highly useful in analyzing linear op-amp circuits.

If there is negative feedback and if the output is not saturated,

1. both inputs are at the same voltage;
2. no current flows in or out of either input.

These rules are true of the ideal op-amp and for practical purposes are true of real op-amps unless very high-speed or high-precision performance is being contemplated (in which case account must be taken of things such as input capacitance, input bias currents and voltages, finite speed, and other op-amp imperfections, discussed in a later section.)

As a consequence of the first rule, the input impedance of the two inputs will be nearly infinite. That is, even if the open-loop impedance between the two inputs is low, the closed-loop input impedance will be high because the inputs will be held at nearly the same voltage. This impedance is considered as infinite for an ideal op-amp and is about one megaohm in practice.

2.5 IDEAL AND REAL OP-AMPS

An ideal op-amp is usually considered to have the following properties, and they are considered to hold for all input voltages:

- Infinite open-loop gain (when doing theoretical analysis, a limit may be taken as open loop gain G goes to infinity)
- Infinite voltage range available at the output (v_{out}) (in practice the voltages available from the output are limited by the supply voltages V_{s+} and V_{s-}).
- Infinite bandwidth (i.e., the frequency magnitude response is considered to be flat everywhere with zero phase shift).
- Infinite input impedance (so, $R_{in} = \infty$, and zero current flows from v_+ to v_-).
- Zero input current (i.e., there is assumed to be no leakage or bias current into the device).
- Zero input offset voltage (i.e., when the input terminals are shorted so that $v_+ = v_-$, the output is a virtual ground or $v_{out} = 0$).

- Infinite slew rate (i.e., the rate of change of the output voltage is unbounded) and power bandwidth (full output voltage and current available at all frequencies).
- Zero output impedance (i.e., $R_{out} = 0$, so that output voltage does not vary with output current).
- Zero noise
- Infinite Common-mode rejection ratio (CMRR)
- Infinite Power supply rejection ratio for both power supply rails.

In practice, none of these ideals can be realized, and various shortcomings and compromises have to be accepted. Depending on the parameters of interest, a real op-amp may be modelled to take account of some of the non-infinite or non-zero parameters using equivalent resistors and capacitors as in Fig. 5, in the op-amp model.

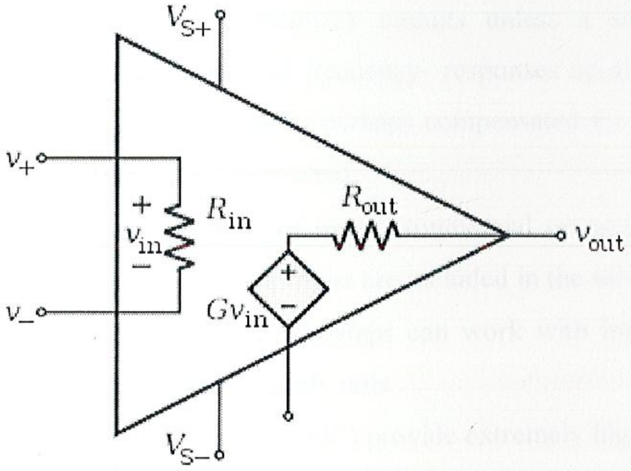


Fig. 5: An equivalent circuit of an operational amplifier that models some resistive non-ideal parameters.

The designer can then include the effects of these undesirable, but real, effects into the overall performance of the final circuit. Some parameters may turn out to have negligible effect on the final design while others represent actual limitations of the final performance.

2.6 CLASSIFICATION OF OPERATIONAL AMPLIFIERS

Op-amps may be classified by their construction:

- discrete (built from individual transistors or tubes/valves)
- IC (fabricated in an Integrated circuit) - most common
- Hybrid

IC op-amps may be classified in many other ways, including:

- Military, Industrial, or Commercial grade (for example: the LM301 is the commercial grade version of the LM101, the LM201 is the industrial version). This may define operating temperature ranges and other environmental or quality factors.
- Classification by package type may also affect environmental hardiness, as well as manufacturing options; DIP, and other through-hole packages are tending to be replaced by Surface-mount devices.
- Classification by internal compensation: op-amps may suffer from high frequency instability in some negative feedback circuits unless a small compensation capacitor modifies the phase- and frequency- responses op-amps with capacitor built in are termed compensated, or perhaps compensated for closed-loop gains down to (say) 5, others: uncompensated.
- Single, dual and quad versions of many commercial op-amp IC are available, meaning 1, 2 or 4 operational amplifiers are included in the same package.
- Rail-to-rail input (and/or output) op-amps can work with input (and/or output) signals very close to the power supply rails.
- CMOS op-amps (such as the CA3140E) provide extremely high input resistances, higher than JFET-input op-amps, which are normally higher than bipolar-input op-amps.
- Other varieties of op-amp include programmable op-amps (simply meaning the quiescent current, gain, bandwidth and so on can be adjusted slightly by an external resistor).
- Manufacturers often tabulate their op-amps according to purpose, such as low-noise pre-amplifiers, wide bandwidth amplifiers, and so on.

2.7 APPLICATIONS

2.7.1 USE IN ELECTRONICS SYSTEM DESIGN

The use of op-amps as circuit blocks is much easier and clearer than specifying all their individual circuit elements (transistors, resistors, etc.), whether the amplifiers used are integrated or discrete. In the first approximation op-amps can be used as if they were ideal differential gain blocks; at a later stage limits can be placed on the acceptable range of parameters for each op-amp.

Circuit design follows the same lines for all electronic circuits. A specification is drawn up governing what the circuit is required to do, with allowable limits. For example, the gain may be required to be 100 times, with a tolerance of 5% but drift of less than 1% in a specified temperature range; the input impedance not less than one megaohm; etc.

A basic circuit is designed, often with the help of circuit modelling (on a computer). Specific commercially available op-amps and other components are then chosen that meet the design criteria within the specified tolerances at acceptable cost. If not all criteria can be met, the specification may need to be modified. A prototype is then built and tested; changes to meet or improve the specification, alter functionality, or reduce the cost, may be made.

2.7.2 BASIC SINGLE STAGE AMPLIFIERS

Single stage amplifiers can be of 3 types:

- Non- inverting amplifier
- Inverting amplifier
- Differential amplifier

2.7.2.1 Non-inverting amplifier

In a non-inverting amplifier, as shown in Fig. 6, the output voltage changes in the same direction as the input voltage. The gain equation for the op-amp is:

$$V_{out} = (V_+ - V_-)\, G_{openloop}$$

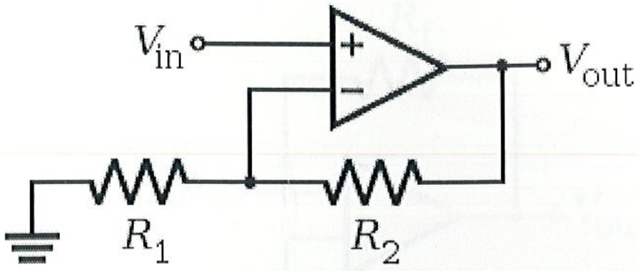


Fig. 6: A non-inverting amplifier

However, in this circuit V_- is a function of V_{out} because of the negative feedback through the R_1R_2 network. R_1 and R_2 form a voltage divider with reduction factor

$$F = \frac{R1}{R1 + R2}$$

Since the V_- input is a high-impedance input, it does not load the voltage divider appreciably, so:

$$V_- = F \cdot V_{out}$$

Substituting this into the gain equation, we obtain:

$$V_{out} = (V_{in} - F.V_{out}) \cdot G_{open\text{-}loop}$$

Solving for V_{out}:

$$V_{out} = V_{in} \left(\frac{1}{F + 1/\ G_{open\text{-}loop}} \right)$$

If $G_{open\text{-}loop}$ is very large, this simplifies to

$$V_{out} = \frac{V_{in}}{F} = V_{in} \Big/ \left(\frac{R_1}{R_1 + R_2} \right) = V_{in} \cdot \left(1 + \frac{R_2}{R_1} \right)$$

2.7.2.2 Inverting amplifier

In an inverting amplifier, as in Fig. 7, the output voltage changes in an opposite direction to the input voltage. This circuit is easily analysed with the help of the two "golden rules".

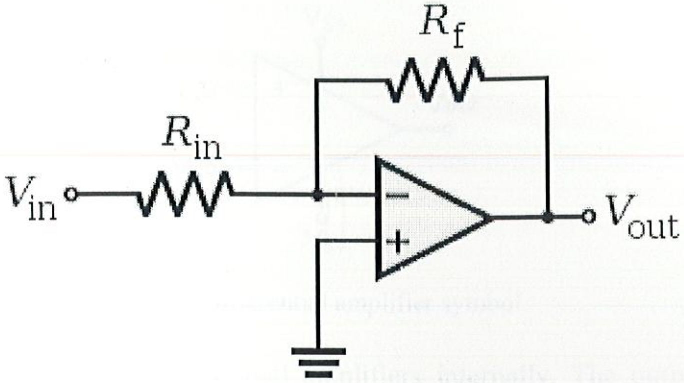


Fig. 7: An inverting amplifier

Since the non-inverting input is grounded, rule 1 tells us that the inverting input will also be at ground potential (0 volts):

$$V_- \approx V_+ = 0$$

The current through R_{in} is then:

$$I_{in} = {}^{V_{in}}\!/_{R_{in}}$$

Rule 2 tells us that no current enters the inverting input. Then, by Kirchoff's current law the current through R_f must be the same as the current through R_{in}. The voltage drop across R_f is then given by Ohm's law:

$$V_{R_f} = R_f . I_{in} = V_{in} \frac{R_f}{R_{in}}$$

Since V_- is zero volts, V_{out} is just $-V_{Rf}$.

$$V_{out} = -V_{in} \frac{R_f}{R_{in}}$$

2.7.2.3 Differential Amplifier

A differential amplifier is a type of electronic amplifier that multiplies the difference between two inputs by some constant factor (the differential gain). The symbol of a typical differential amplifier is shown in Fig. 8

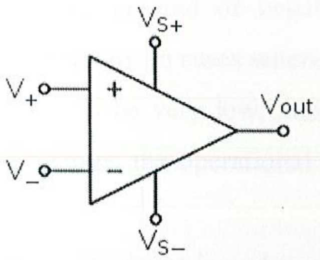


Fig. 8: Differential amplifier symbol

Many electronic devices use differential amplifiers internally. The output of an ideal differential amplifier is given by:

$$V_{out} = A_d\,(V_{in}^{+} - V_{in}^{-})$$

Where V_{in}^{+} and V_{in}^{-} are the input voltages and A_d is the differential gain. In practice, however, the gain is not quite equal for the two inputs. This means, for instance, that if V_{in}^{+} and V_{in}^{-} are equal, the output will not be zero, as it would be in the ideal case. A more realistic expression for the output of a differential amplifier thus includes a second term.

$$V_{out} = A_d\,(V_{in}^{+} - V_{in}^{-}) + A_c\left(\frac{V_{in}^{+} + V_{in}^{-}}{2}\right)$$

A_c is called the common-mode gain of the amplifier. As differential amplifiers are often used when it is desired to null out noise or bias-voltages that appear at both inputs, a low common-mode gain is usually considered good.

2.8 LIMITATIONS OF REAL OP-AMPS

Real op-amps differ from the ideal model in various respects. IC op-amps as implemented in practice are moderately complex integrated circuits.

2.8.1 DC IMPERFECTIONS

Real operational amplifiers suffer from several non-ideal effects:

- **Finite gain**: Open-loop gain is infinite in the ideal operational amplifier but finite in real operational amplifiers. Typical devices exhibit open-loop DC gain ranging from 100,000 to over 1 million. So long as the loop gain (i.e., the product of open-loop and feedback gains) is very large, the circuit gain will be determined entirely by the amount of negative feedback (i.e., it will be independent of open-loop gain). In cases where closed-loop gain must be very high, the feedback gain will be very low, and the low feedback gain causes low loop gain; in these cases, the operational amplifier will cease to behave ideally.

- **Finite input impedance** : The input impedance of the operational amplifier is defined as the impedance between its two inputs. It is not the impedance from each input to ground. In the typical high-gain negative-feedback applications, the feedback ensures that the two inputs sit at the same voltage, and so the impedance between them is made artificially very high. Hence, this parameter is rarely an important design parameter. Because MOSFET-input operational amplifiers often have protection circuits that effectively short circuit any input differences greater than a small threshold, the input impedance can appear to be very low in some tests. However, as long as these operational amplifiers are used in a typical high-gain negative feedback application, these protection circuits will be inactive and the negative feedback will render the input impedance to be practically infinite. The input bias and leakage currents described below are a more important design parameter for typical operational amplifier applications.
- **Non-zero output impedance** : Low output impedance is important for low resistance loads; for these loads, the voltage drop across the output impedance of the amplifier will be significant. Hence, the output impedance of the amplifier reflects the maximum power that can be provided. If the output voltage is fed back negatively, the output impedance of the amplifier is effectively lowered; thus, in linear applications, op-amps usually exhibit very low output impedance indeed. Negative feedback cannot, however, reduce the limitations that R_{load} in conjunction with R_{out} place on the maximum and minimum possible output voltages; it can only reduce output errors within that range. Low-impedance outputs typically require high quiescent (i.e., idle) current in the output stage and will dissipate more power, so low-power designs may purposely sacrifice low output impedance.

- **Input current** : Due to biasing requirements or leakage, a small amount of current (typically ~10 nanoamperes for bipolar op-amps, tens of picoamperes for JFET input stages, and only a few pA for MOSFET input stages) flows into the inputs. When large resistors or sources with high output impedances are used in the circuit, these small currents can produce large unmodeled voltage drops. If the input currents are matched, and the impedance looking out of both inputs are matched, then the voltages produced at each input will be equal. Because the operational amplifier operates on the difference between its inputs, these matched voltages will have no effect (unless the operational amplifier has poor CMRR, which is described below). It is more common for the input currents (or the impedances looking out of each input) to be slightly mismatched, and so a small offset voltage can be produced. This offset voltage can create offsets or drifting in the operational amplifier. It can often be nulled externally; however, many operational amplifiers include offset null or balance pins and some procedure for using them to remove this offset. Some operational amplifiers attempt to nullify this offset automatically.
- **Input offset voltage** : This voltage, which is what is required across the op-amp's input terminals to drive the output voltage to zero, is related to the mismatches in input bias current. In the perfect amplifier, there would be no input offset voltage. However, it exists in actual op-amps because of imperfections in the differential amplifier that constitutes the input stage of the vast majority of these devices. Input offset voltage creates two problems: First, due to the amplifier's high voltage gain, it virtually assures that the amplifier output will go into saturation if it is operated without negative feedback, even when the input terminals are wired together. Second, in a closed loop, negative feedback configuration, the input offset voltage is amplified along with the signal and this may pose a problem if high precision DC amplification is required or if the input signal is very small.
- **Common mode gain** : A perfect operational amplifier amplifies only the voltage difference between its two inputs, completely rejecting all voltages that are common to both. However, the differential input stage of an

operational amplifier is never perfect, leading to the amplification of these identical voltages to some degree. The standard measure of this defect is called the common-mode rejection ratio (denoted CMRR). Minimization of common mode gain is usually important in non-inverting amplifiers (described below) that operate at high amplification.

- **Temperature effects** : All parameters change with temperature. Temperature drift of the input offset voltage is especially important.
- **Power-supply rejection** : The output of a perfect operational amplifier will be completely independent from ripples that arrive on its power supply inputs. Every real operational amplifier has a specified power supply rejection ratio (PSRR) that reflects how well the op-amp can reject changes in its supply voltage. Copious use of bypass capacitors can improve the PSRR of many devices, including the operational amplifier.
- **Drift** : Real op-amp parameters are subject to slow change over time and with changes in temperature, input conditions, etc.

2.8.2 AC IMPERFECTIONS

The op-amp gain calculated at DC does not apply at higher frequencies. To a first approximation, the gain of a typical op-amp is inversely proportional to frequency. This means that an op-amp is characterized by its gain-bandwidth product. For example, an op-amp with a gain bandwidth product of 1 MHz would have a gain of 5 at 200 kHz, and a gain of 1 at 1 MHz This low-pass characteristic is introduced deliberately, because it tends to stabilize the circuit by introducing a dominant pole. This is known as frequency compensation.

Typical low cost, general purpose op-amps exhibit a gain bandwidth product of a few megahertz. Specialty and high speed op-amps can achieve gain bandwidth products of hundreds of megahertz. For very high-frequency circuits, a completely different form of op-amp called the current-feedback operational amplifier is often used.

CHAPTER-3

CDTA

In the last decade, there has been much effort to reduce the supply voltage of electronic circuits. This is due to the command for portable and battery- powered equipment. Since a low-voltage operating circuit becomes necessary, the current mode technique is ideally suited for this purpose more than the voltage-mode one. Consequently, there is a growing interest in synthesizing the current-mode circuits because of their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and low power consumption.

A 5-terminals active element, Current Differencing Transconductance Amplifier (CDTA), seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filter [3]. It is current-mode element whose input and output signals are currents. The active circuit component CDTA is particularly useful for the current-mode applications, because its input and output signals are currents. CDTA consists of the input current-differencing unit and of multiple-output Operational Transconductance Amplifier (OTA). Because of high current gain of the CDTA which is comparable to voltage gain of a classical voltage-feedback operational amplifier.

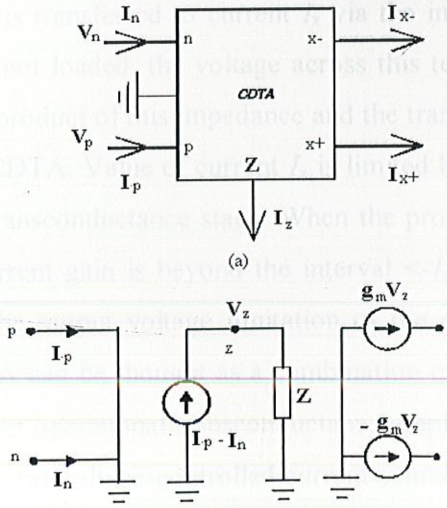


Fig. 9: The CDTA (*a*) Symbol, (*b*) Equivalent circuit.

The contemporary active elements such as OTA, second generation current conveyor, current feedback amplifier, four terminal floating null or etc are used to realize different filtering functions. These active devices have either high input impedance and high output impedance or high input impedance and low output impedance. The requirement for current mode circuits is low input (ideally zero) and high output (ideally infinite). Accordingly, the recently introduced active device namely CDTA, having low input and high output impedances is highly desirable active device for the implementation of signal processing in current mode. This element consists of a unity-gain current source controlled by the difference of the input currents and a multi-output transconductance amplifier providing electronic tenability through its transconductance gain. The use of CDTA as active component simplifies the implementation thereby providing the circuits with lesser number of passive components vis-à-vis its counterparts leading to compact structures in some applications. Some realizations using CDTA as active element operating in current-mode have been developed.

3.1 THEORY

3.1.1 BASIC CONCEPT OF CDTA

The CDTA element has a couple of low-impedance input terminals p and n. The difference of currents I_p and I_n flows out of the z terminal into an outside load, causing the voltage drop which is transferred to current I_x via the internal transconductance g_m. When the z terminal is not loaded, the voltage across this terminal is given by its high internal resistance. The product of this impedance and the transconductance g_m represents the current gain of the CDTA. Value of current I_x is limited by internal current source I_c, which is a part of the transconductance stage. When the product of the difference input current I_p-I_n and the current gain is beyond the interval $<-I_c, I_c>$, the current I_x will be clipped, analogous to the output voltage limitation of the operational amplifier in the saturation regime. CDTA can be thought as a combination of a current differencing unit followed by a dual-output operational transconductance amplifier, DO-OTA. Ideally, the OTA is assumed as an ideal voltage-controlled current source and can be described by $I_x = g_m.(V_+ - V_-)$, where I_x is output current, V_+ *and* V_- denote non-inverting and inverting input voltage of the OTA, respectively. Note that gm is a function of the bias current. When this element is used in CDTA, one of its input terminals is grounded (e.g., $V_- = 0V$). With dual output availability, $I_{x+} = -I_{x-}$ condition is assumed.

3.1.2 CIRCUIT ANALYSIS

The schematic symbol and equivalent circuit of the CDTA are shown in Fig. 9(*a*) and (*b*). The inputs p and n produce difference current which is transferred to the z terminal is converted into a set of output currents by a dual output transconductance stage. The port relationships are given by:

$$V_p = V_n = 0,$$

$$I_z = I_p = -I_n,$$

$$I_{x+} = g_m.V_z,$$

$$I_{x-} = -g_m.V_z.$$

where $V_{z-} = I_z.Z_z$ and

Z_Z is the external impedance connected to z terminal of the CDTA.

*V*p, *V*n and *V*z represents the voltages at p, n and z terminals respectively.

CDTA can be implemented using the bipolar transistors as shown in Fig. 10. The transistors *T*1-*T*11 forms the input stage, i.e. the current differencing circuit followed by a transconductance amplifier implemented by employing transistors *T*12-*T*24.

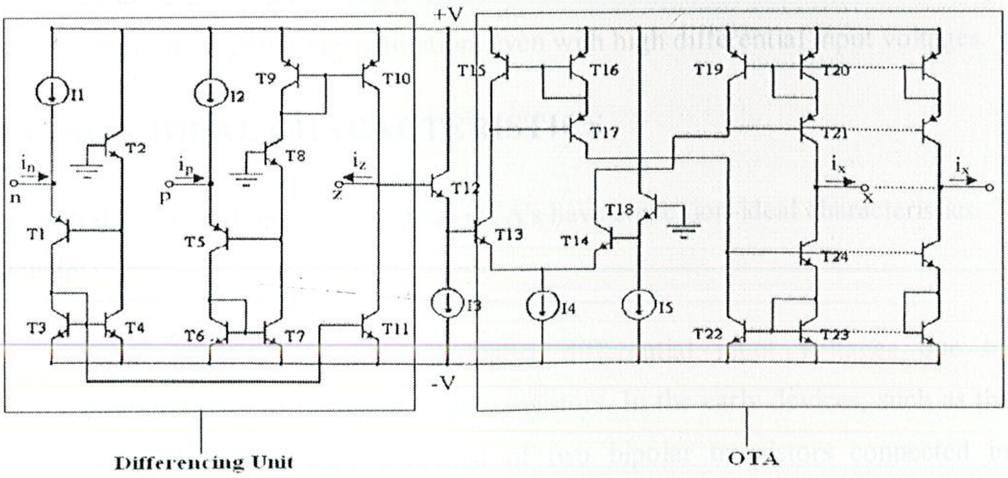


Fig. 10: The CDTA Internal circuit.

The operational transconductance amplifier is an amplifier whose differential input voltage produces an output current. Thus, it is a voltage controlled current source (VCCS). There is usually an additional input for a current to control the amplifier's transconductance. The OTA is similar to a standard operational amplifier in that it has a high impedance differential input stage and that it may be used with negative feedback.

The first commercially available integrated circuit units were produced by RCA in 1969 (before being acquired by General Electric), in the form of the CA3080, and they have been improved since that time. Although most units are constructed with bipolar transistors, field effect transistor units are also produced. The OTA is not as useful by itself in the vast majority of standard op-amp functions as the ordinary op-amp because its output is a current. One of its principal uses is in implementing electronically controlled applications such as variable frequency oscillators and filters and variable gain amplifier stages which are more difficult to implement with standard op-amps.

3.2 PRINCIPAL DIFFERENCES FROM STANDARD OPERATIONAL AMPLIFIERS

- Its output of a current contrasts to that of standard operational amplifier whose output is a voltage.
- It is usually used "open-loop"; without negative feedback in linear applications. This is possible because the magnitude of the resistance attached to its output controls its output voltage. Therefore a resistance can be chosen that keeps the output from going into saturation, even with high differential input voltages.

3.3 NON-IDEAL CHARACTERISTICS

As with the standard op-amp, practical OTA's have some non-ideal characteristics. These include:

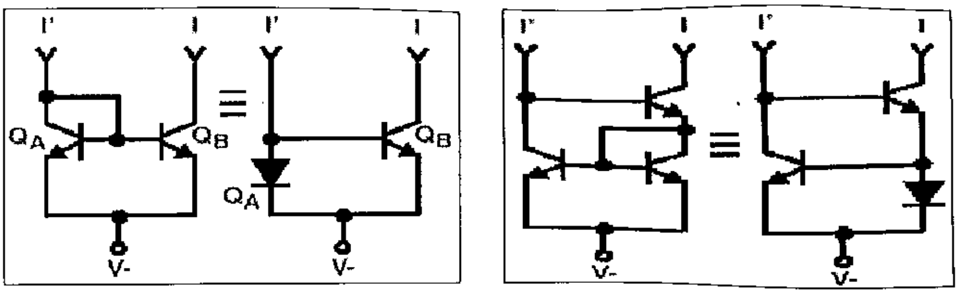
- Input stage non-linearity at higher differential input voltages due to the characteristics of the input stage transistors. In the early devices, such as the CA 3080, the input stage consisted of two bipolar transistors connected in the differential amplifier configuration. The transfer characteristics of this connection are approximately linear for differential input voltages of 20 mV or less, this is an important limitation when the OTA is being used open loop as there is no negative feedback to linearize the output. One scheme to improve this parameter is mentioned below.

- Temperature sensitivity of transconductance.
- Variation of input and output impedance, input bias current and input offset voltage with the transconductance control current I_{abc}.

3.4 FUNCTION OF CURRENT MIRROR IN OTA

To understand the OTA, you have to know what a ***current mirror*** is. The current mirror was a natural development of integrated circuit op amps in which transistors could be made that was inherently matched. Fig. 11(*a*) shows a simple current mirror. Let us assume that V_- is connected to ground, and that a resistor is connected from +12 to the collector of Q_A. The collector of Q_A is connected to the base, so that there is just a diode drop from collector to emitter. The base voltage adjusts itself so that the sum of the base current and the collector current (beta times the base) is equal to the current defined by the resistor. Let us assume that the diode drop is 0.6 volts. Thus, the voltage across the resistor is about 11.4 volts, and we can select the value of resistor to give us whatever current we like. Since the transistors are monolithic and matched, whatever collector current V_{BE} of Q_A defines, the same collector current will flow in Q_B, which sees the same V_{BE}. Transistor Q_A acts like a diode, as shown in the right side of Fig. 11(*a*).

Thus, for the current mirror, current is 'pushed' from above into the diode (blown), and a very nearly equal current is "pulled" to a low voltage (sucked). The current I' is slightly larger than, it must also provide base current for both transistors. If beta were 100, one part in 100 would go to each base for an error of about 2%. The accuracy of the mirror can be enhanced significantly by using a more complex mirror, which uses a third transistor. The improved current mirror is shown in Fig. 11(*b*). Most monolithic current mirrors use the improved circuit. To summarize, 'blow' into an NPN current mirror from above, and the output sucks an equal current from below. Note, no resistors are required to make a current mirror. By using PNP transistors, make a current mirror in which it 'suck' current from below and the mirror 'blows' an equal current from above.



(*a*) (*b*)

Fig. 11: Basic types of Current Mirrors: (*a*) Diode-connected transistor paired with transistor (*b*) Improved version: employing an extra transistor

CHAPTER-4

APPLICATIONS

The continuous-time Current mode circuits offer several potential advantages like simplicity of the circuit, higher frequency operations and wider dynamic range as compared to the voltage mode circuits. We have implemented a few applications through both, Op-amp as well as CDTA here to prove these advantages true.

4.1 COMPARATORS

4.1.1 INTRODUCTION

A comparator is a device which compares two voltages or currents at the input and switches the output to indicate which is larger. The input voltages must not exceed the power voltage range:

$$V_{S-} \leq V_+ \ , V_- \leq V_{S+}$$

Op-amp implementation of voltage comparator

An operational amplifier has a well balanced difference input and a very high gain. The parallels in the characteristics allow the op-amps to serve as comparators in some functions.

A voltage comparator is basically a high-gain differential amplifier. The differential amplifier operates as a 'switch' in comparator circuit [8]. A comparator can be thought of as a fast, high-gain op-amp which is not used with negative feedback. The comparator has large open-loop gain A. The function of a comparator is to decide which of the two inputs has larger voltage.

$$v_{out} = A(v_+ - v_-) = \begin{cases} V_{\max} & v_+ > v_- \\ -|V_{\min}| & v_+ < v_- \end{cases}$$

where $V_{\max}$ and $V_{\min}$ are approximately the power supply voltages. Therefore, the comparator converts an analog input signal into an output with two possible states.

Hence, this can be thought of as a 1-bit analog to digital converter (A/D or ADC). There is more gain at high frequency, meaning faster response. Also, the amplifier can be optimized for speed at the expense of linearity. The op-amp makes an excellent voltage comparator when operating speed is not critical , Especially in view of extremely high gain (>10) of certain Op-Amp types. Fig. 12 shows a comparator implemented using op-amp.

The op-amp should fulfill the following requirements when used as a comparator. The output must switch rapidly between saturation levels and also respond instantly to any change of conditions at its inputs. This requires wide bandwidth. High voltage gain is required to have smaller hysteresis voltage. A high CMRR is required to reject the CM voltages, such as noise, at the input terminals of the comparator. The input offset currents and input offset voltage must be negligible, also the changes in these offsets due to temperature variant should be very slight. The output must swing between two logic levels, suitable for certain logic family such as TTL. The output transition takes place instantaneously. Such effects are more traceable at high frequencies, where the output switching time can be comparable to or even larger than the input period itself. Here we are using compensated 741 Op-Amp which employs an on-chip capacitor which stabilizes the device against possible oscillation when used with negative feedback, i.e., operated in closed loop condition.

In comparator applications, however, such Op-Amp is operated in the open-loop condition, so that the frequency compensation using the capacitor is not needed. In fact, the compensating capacitor is detrimental in comparator operation because it slows down the response unnecessarily.

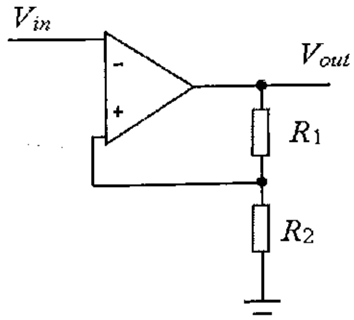


Fig. 12: The implemented Comparator using Op-amp 741 IC

In practice, using an operational amplifier as a comparator presents several disadvantages as compared to using a dedicated comparator:

- Op-amps are designed to operate in the linear mode with negative feedback. Hence, an op-amp typically has a lengthy recovery time from saturation. Almost all op-amps have an internal compensation capacitor which imposes slew rate limitations for high frequency signals. Consequently an op-amp makes a sloppy comparator with propagation delays that can be as slow as tens of microseconds.
- Since op-amps do not have any internal hysteresis an external hysteresis network is always necessary for slow moving input signals.
- The quiescent current specification of an op-amp is valid only when the feedback is active. Some op-amps show an increased quiescent current when the inputs are not equal.
- A comparator is designed to produce well limited output voltages that easily interface with digital logic. Compatibility with digital logic must be verified while using an op-amp as a comparator.

4.1.2 CURRENT COMPARATOR EMPLOYING THE CDTA ELEMENT:

The CDTA element has a couple of low-impedance input terminals p and n. The difference of currents I_p and I_n flows out of the z terminal into an outside load, causing the voltage drop which is transferred to current I_x via the internal transconductance g_m. When the z terminal is not loaded, the voltage across this terminal is given by its high [4] internal resistance. The product of this impedance and the transconductance g_m represents the current gain of the CDTA. The implemented comparator using CDTA is shown in Fig. 13. Value of current I_x is limited by internal current source I_c, which is a part of the transconductance stage. When the product of the difference input current I_p-I_n and the current gain is beyond the interval <-I_c, I_c>, the current I_x will be clipped, analogous to the output voltage limitation of the operational amplifier in the saturation regime.

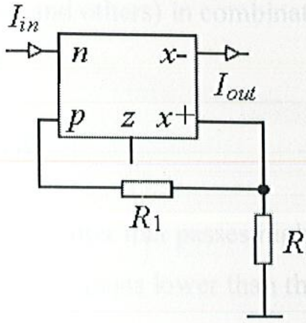


Fig. 13: The implemented Comparator using CDTA

4.1.3 APPLICATIONS OF COMPARATORS

1. **Null detectors :** A null detector is one that functions to identify when a given value is zero. Comparators can be a type of amplifier distinctively for null comparison measurements. It is the equivalent to a very high gain amplifier with well-balanced inputs and controlled output limits. The circuit compares the two input voltages, determining the larger. The inputs are an unknown voltage and a reference voltage, usually referred to as v_u and v_r. A reference voltage is generally on the non-inverting input (+), while v_u is usually on the inverting input (-).

2. **Zero-crossing detectors :** For this type of detector, a comparator detects each time an **ac** pulse changes polarity. The output of the comparator changes state each time the pulse changes its polarity, that is, the output is high for a positive pulse and low for a negative pulse. The comparator also amplifies and squares the input signal.

3. **Relaxation oscillator :** A comparator can be used to build a relaxation oscillator. It uses both positive and negative feedback. The positive feedback is a Schmitt trigger configuration.

4. **Analog to Digital Converters :** When a comparator performs the function of telling if an input voltage is above or below a given threshold, it is essentially performing a 1-bit quantization. This function is used in nearly all analog to digital converters (such as Flash, Pipeline, SAR, Delta Sigma, Folding,

Interpolating, Dual-slope and others) in combination with other devices to achieve a multi-bit quantization.

4.2 HIGH-PASS FILTER

A high-pass filter (HPF), is an LTI filter that passes high frequencies well but attenuates (i.e., reduces the amplitude of) frequencies lower than the filter's cutoff frequency. The actual amount of attenuation for each frequency is a design parameter of the filter. It is sometimes called a low-cut filter or bass-cut filter. It can be implemented using op-amp 741 IC(Fig. 14) and op-amp(Fig.15).

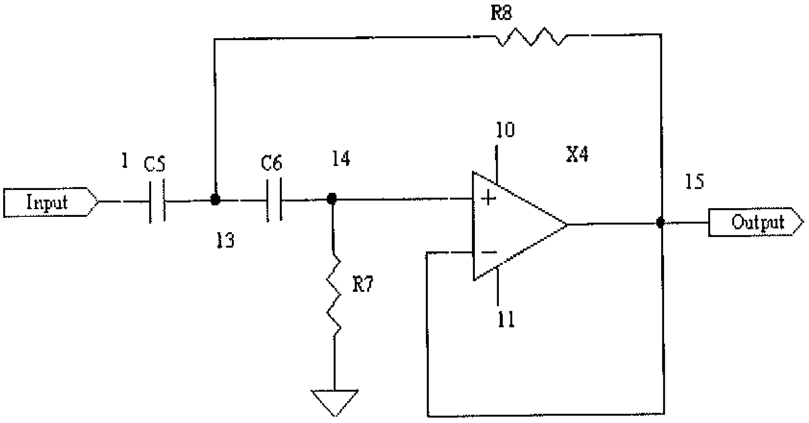


Fig. 14: The implemented High –Pass Filter using Op-amp 741 IC

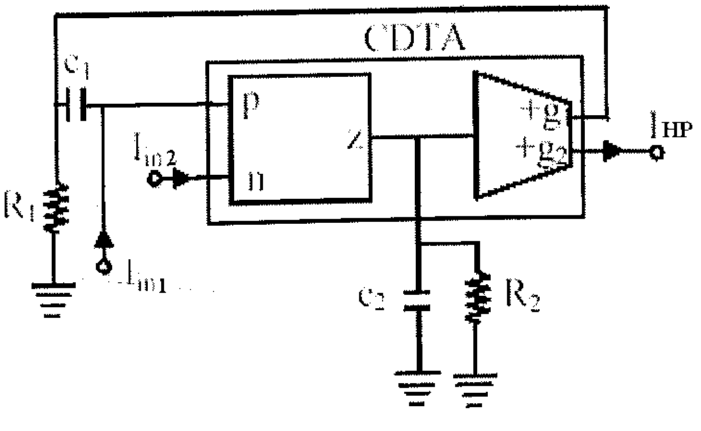


Fig. 15: The implemented High –Pass Filter using CDTA

4.2.1 APPLICATIONS OF HIGH-PASS FILTERS

1. **Audio :** High-pass filters have many applications. They are used as part of an audio crossover to direct high frequencies to a tweeter while attenuating bass signals which could interfere with, or damage, the speaker. When such a filter is built into a loudspeaker cabinet it is normally a passive filter that also includes a low-pass filter for the woofer and so often employs both a capacitor and inductor.
2. **Rumble filters** : These are high-pass filters applied to the removal of unwanted sounds near to the lower end of the audible range or below. For example, noises (e.g., footsteps, or motor noises from record players and tape decks) may be removed because they are undesired.
3. High-pass filters are also used for AC coupling at the inputs of many audio amplifiers, for preventing the amplification of DC currents which may harm the amplifier, rob the amplifier of headroom, and generate waste heat at the loudspeakers voice coil
4. **Image Processing :** High-pass and low-pass filters are also used in digital image processing to perform transformations in the spatial frequency domain. The so-called Unsharp Mask used in most of the image editing software is a high pass filter.

4.3 LOW-PASS FILTER

A low-pass filter (LPF) is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. An ideal low-pass filter completely eliminates all frequencies above the cutoff frequency while passing those below unchanged: its frequency response is a rectangular function, and is a brick-wall filter. The transition region present in practical filters does not exist in an ideal filter. The order of the filter determines the amount of additional attenuation for frequencies higher than the cutoff frequency. A first-order filter, for example, will reduce the signal amplitude by half, i.e. the power roll off approaches 20 dB per decade in the limit of high frequency. A second-order filter attenuates higher frequencies more steeply.

This second order LPF can be implemented using op-amp, as in Fig. 16 and CDTA, as in Fig. 17.

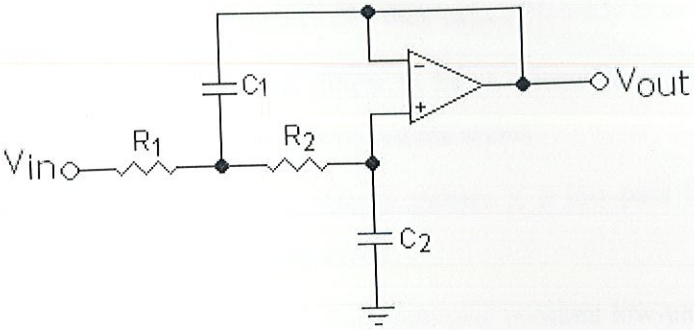


Fig. 16: The implemented Low–Pass Filter using Op-amp 741 IC

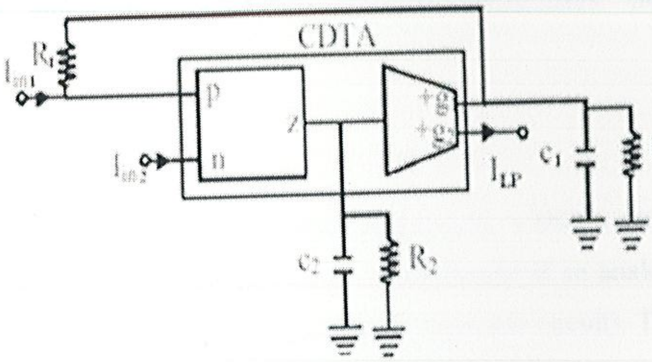


Fig. 17: The implemented Low–Pass Filter using CDTA

4.3.1 APPLICATIONS OF LOW-PASS FILTERS

1. **Acoustic** : A stiff physical barrier tends to reflect higher sound frequencies, and so acts as a low-pass filter for transmitting sound. When music is playing in another room, the low notes are easily heard, while the high notes are attenuated.
2. **Electronic** : In an electronic low-pass RC filter for voltage signals, high frequencies contained in the input signal are attenuated but the filter has little attenuation below its cutoff frequency which is determined by its RC time constant.
3. For current signals, a similar circuit using a resistor and capacitor in parallel

works in a similar manner. See current divider discussed in more detail below.

4. Electronic low-pass filters are used to drive subwoofers and other types of loudspeakers, to block high pitches that they can't efficiently broadcast.
5. Radio transmitters use low-pass filters to block harmonic emissions which might cause interference with other communications.
6. The tone knob found on many electric guitars is a low-pass filter used to reduce the amount of treble in the sound.
7. An integrator is another example of a single time constant low-pass filter.
8. Low-pass filters also play a significant role in the sculpting of sound for electronic music as created by analogue synthesizers. See subtractive synthesis.

4.4 BAND-PASS FILTER

A band-pass filter (BPF) is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. An example of an analogue electronic band-pass filter is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a low-pass filter with a high-pass filter.

Band pass is an adjective that describes a type of filter or filtering process; it is frequently confused with pass band, which refers to the actual portion of affected spectrum. The two words are both compound words that follow the English rules of formation: the primary meaning is the latter part of the compound, while the modifier is the first part. Hence, one may correctly say 'A dual band pass filter has two pass bands'.

An ideal band pass filter would have a completely flat pass band (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the pass band. Additionally, the transition out of the pass band would be instantaneous in frequency. In practice, no band pass filter is ideal second order BPF can be implemented using op-amp and CDTA as in Fig. 18 and 19 respectively. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended pass band where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band ripple.

The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies.

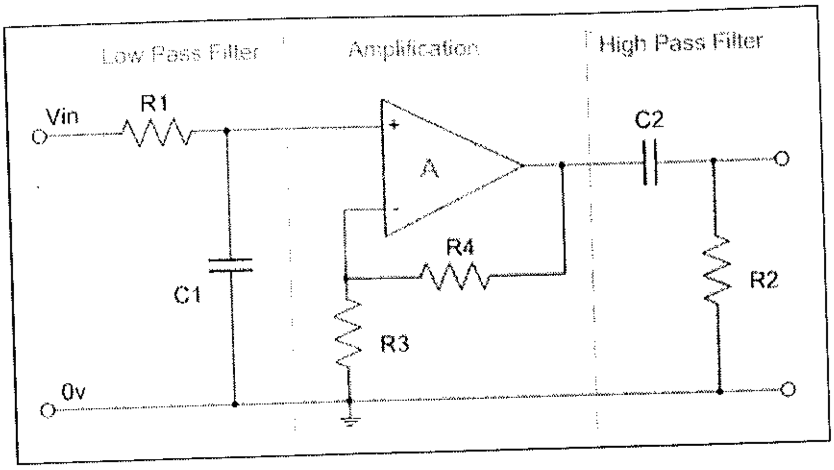


Fig. 18: The implemented Band Pass Filter using Op-amp 741 IC

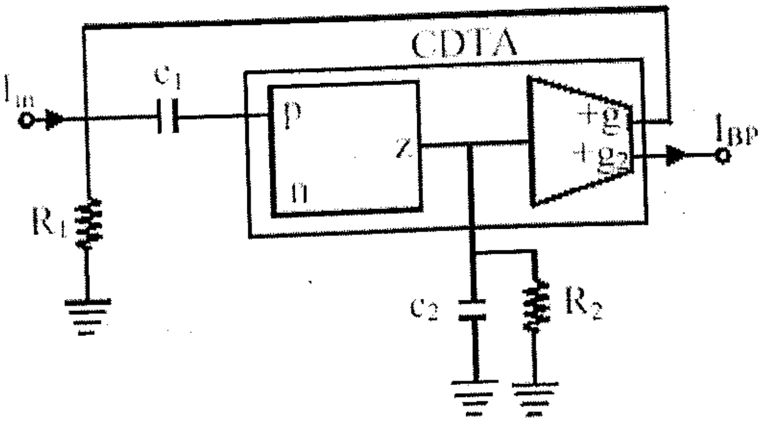


Fig. 19: The implemented Band Pass Filter using Op-amp 741 IC

4.4.1 APPLICATIONS OF BAND-PASS FILTERS

1. Outside of electronics and signal processing, one example of the use of band-pass filters is in the atmospheric sciences. It is common to band-pass filter recent meteorological data with a period range of, for example, 3 to 10 days, so that only cyclones remain as fluctuations in the data fields.
2. In neuroscience, visual cortical simple cells were first shown by David Hubel and Torsten Wiesel to have response properties that resemble Gabor filters, which are band-pass.

4.5 QUADRATURE OSCILLATORS

Oscillator is an important basic building block, frequently employed in electrical engineering applications [5]. Among several kinds of oscillator, the quadrature oscillator is widely used because it can offer sinusoidal signals with 90° phase difference, for example, in telecommunications for quadrature mixers and single-sideband modulators. It can be implemented using op-amp (Fig. 20) and CDTA (Fig. 21).

Quadrature oscillator generates two sine-wave signals, but one signal is shifted 90 degree from the other signal. One output that leads the other called cosine signal, and the other is sine.

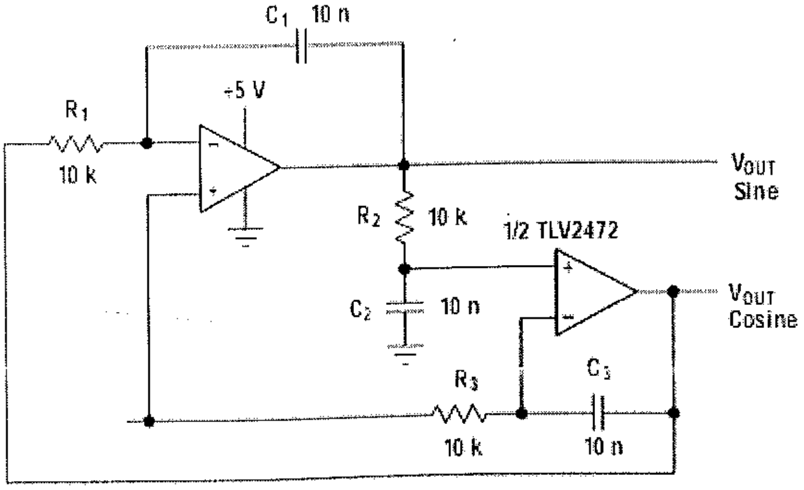


Fig. 20: The implemented Quadrature Oscillator using Op-amp 741 IC

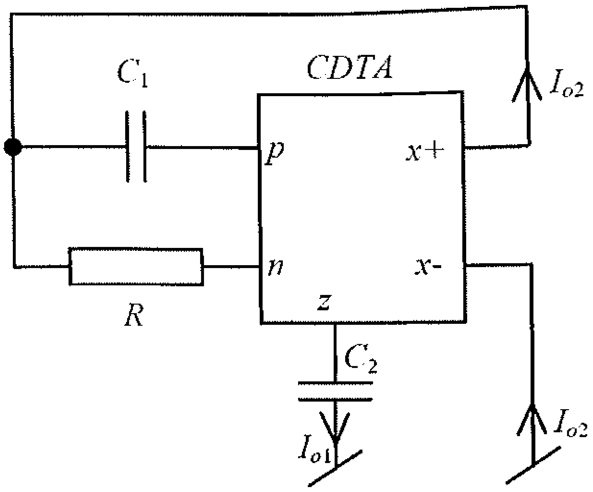
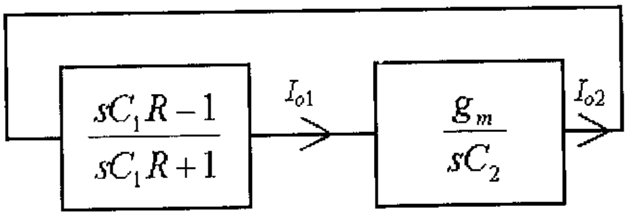


Fig. 21: The implemented Band Pass Filter using CDTA

This circuit construction consists of a single CDTA, one resistor, and two capacitors. The quadrature oscillator is designed by cascading a first-order all-pass filter and a non-inverting integrator [1]. The block diagram of this circuit is shown below



Therefore, the characteristic equation of this oscillator is:

$$s^2C_1C_2R+s(C_2-C_1g_mR)+g_m=0$$

From the above equation, it can be seen that the proposed circuit can produce oscillations if the oscillation condition is fulfilled

$$g_mR = C_2/C_1$$

For example, this condition can be achieved by setting

$$C_1=C_2 \quad \text{and} \quad R=1/g_m$$

Then the characteristic equation of the system becomes

$$s^2 C_1 C_2 R + g_m = 0$$

The oscillation frequency is as follows:

$$\omega_{osc} = \sqrt{(g_m / C_1 C_2 R)}$$

4.5.1 APPLICATIONS OF QUADRATURE OSCILLATORS

Quadrature oscillators can be used in telecommunications for:

1. Quadrature mixers
2. Single-sideband modulator

CHAPTER-5

SOFTWARE USED: PSPICE A/D

PSpice A/D is a simulation program that models the behavior of a circuit containing any mix of analog and digital devices. It can be thought of as a software-based breadboard of a circuit that can be used to test and refine the design before ever touching a piece of hardware.

Because the analog and digital simulation algorithms are built into the same program, PSpice A/D simulates mixed-signal circuits with no performance degradation because of tightly coupled feedback loops between the analog and digital sections [6].

PSpice A/D can perform the following types of analyses:

- AC, DC, and transient analyses, to help test the response of the circuit to different inputs
- Parametric, Monte Carlo, and sensitivity/worst-case analyses, to see how circuit's behavior varies with changing component values
- Digital worst-case timing analysis to help find timing problems that occur with only certain combinations of slow and fast signal transmissions.

5.1 CREATING DESIGNS FOR SIMULATION

In order to simulate a design with PSpice that is created in OrCAD Capture, you must begin the project as an analog type intended for simulation [6]. Existing projects in Capture cannot be simulated without special modifications.

5.1.1 TO CREATE A NEW PROJECT FOR SIMULATION

1. From the File menu in Capture's Project Manager, point to New and select Project. The New Project dialog box appears.
2. In the Name text box, enter the name for the new project.

3. Under the Create a New Project Using frame, select Analog or Mixed-Signal Circuit Wizard. Create a project (not a design) and select the Analog or Mixed-Signal Circuit Wizard option in order to be able to simulate the new design with PSpice.
4. In the Location text box, enter the path where you want the new project files to be stored, or use the Browse button to locate the directory.
5. Click OK.
6. Enter any special libraries to be included, if necessary, and click Finish to create the new project directory and open the schematic page editor.

A design that is targeted for simulation has:

- parts for which there are simulation models available and configured
- sources of stimulus to the circuit

When creating designs for both simulation and printed circuit board layout, some of the parts you use are for simulation only [6] (that is, simulation stimulus parts like voltage sources), and some of the parts you use have simulation models that only model some of the pins of a real device.

5.1.2 CREATING A NEW SIMULATION PROFILE

A simulation profile (*.SIM) saves your simulation settings for an analysis type so you can reuse them easily.

You can create a new simulation profile from scratch or import the settings from an existing simulation profile. Importing settings from existing simulation profiles allows you to reuse the settings from other simulation profiles.

5.1.2.1 Steps

1. From the File menu in PSpice, point to New and choose Simulation Profile to display the New Simulation dialog box.

2. In the Profile Name text box, type a name for the profile (such as the name of the analysis type for the new profile).
3. In the Inherit from an Existing Profile text box, enter the name of another profile to import its settings into the new profile. You must enter an existing profile name in this text box or click browse to select an existing profile.
4. Click Create to create the profile and display the Simulation Settings dialog box.

5.1.3 CREATING A SIMULATION NETLIST

5.1.3.1 Overview

A netlist is the connectivity description of a circuit, showing all of the components, their interconnections, and their values. When you create a simulation netlist from OrCAD Capture, that netlist describes the current design.

The flat netlist is generated for all levels of hierarchy, starting from the top, regardless of whether you are pushed into any level of the hierarchy. Flat netlists are most commonly used as input to PCB layout tools. The flat simulation netlist format for PSpice contains device entries for all parts on a sub circuit (child) schematic multiple times, once for each instance of the hierarchical part or block used.

5.1.3.2 Creating the netlist

We can generate a simulation netlist in one of two ways:

- from Capture's Project Manager by using the Create Netlist command under the Tools menu or
- directly from within Capture itself by using the Create Netlist command under the PSpice menu

During the netlist process, Capture creates files with different extensions: the .NET file contains the netlist; the .ALS file contains alias information for cross-probing.

5.1.4 VIEWING RESULTS

From Capture's PSpice menu, choose View Simulation Results.

To automatically start PSpice after simulation:

1. In Capture's PSpice menu, choose Edit Simulation Settings to display the Simulation Settings dialog for the currently active profile.
2. Click the Probe Window tab, then select Display Probe window after simulation has completed.
3. Select any other options you want to use.
4. Click OK.

CHAPTER-6

RESULTS AND DISCUSSIONS

6.1 OP-AMP

6.1.1 IMPLEMENTATION OF LPF

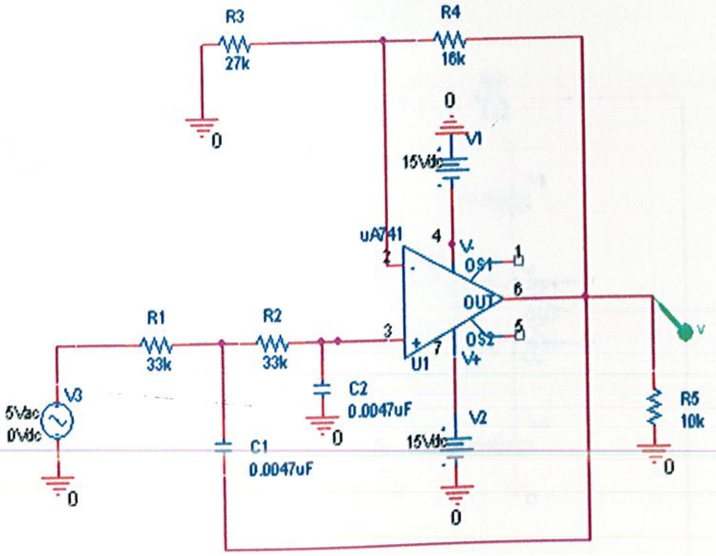
Second order filters are important because higher order filters can be designed using them. Fig. 22 shows an implementation of LPF [8]. The gain of second order filters is set by R_3 and R_4, while the high cut-off frequency f_H is determined by R_1, C_1, R_2, and C_2 as follows:

$$f_H = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

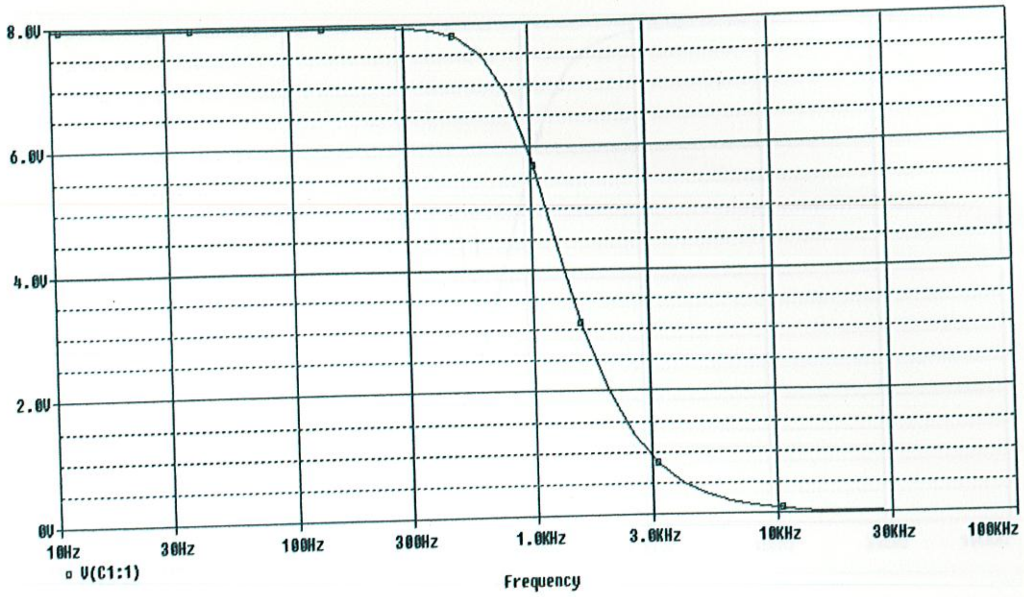
And,

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+(f/f_H)^4}}$$

where $A_F = 1.586$



(*a*)



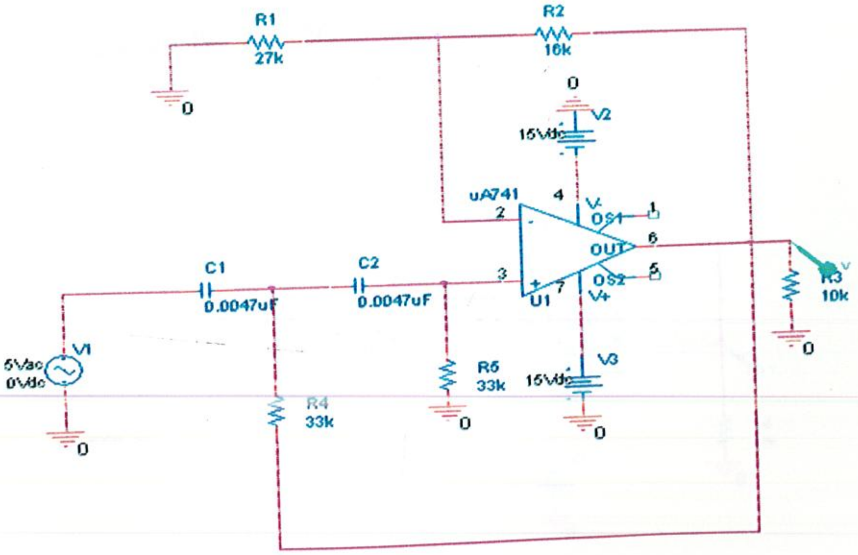
(*b*)

Fig. 22: Operational Amplifier second order low pass filter (*a*) circuit realization, (*b*) output waveform.

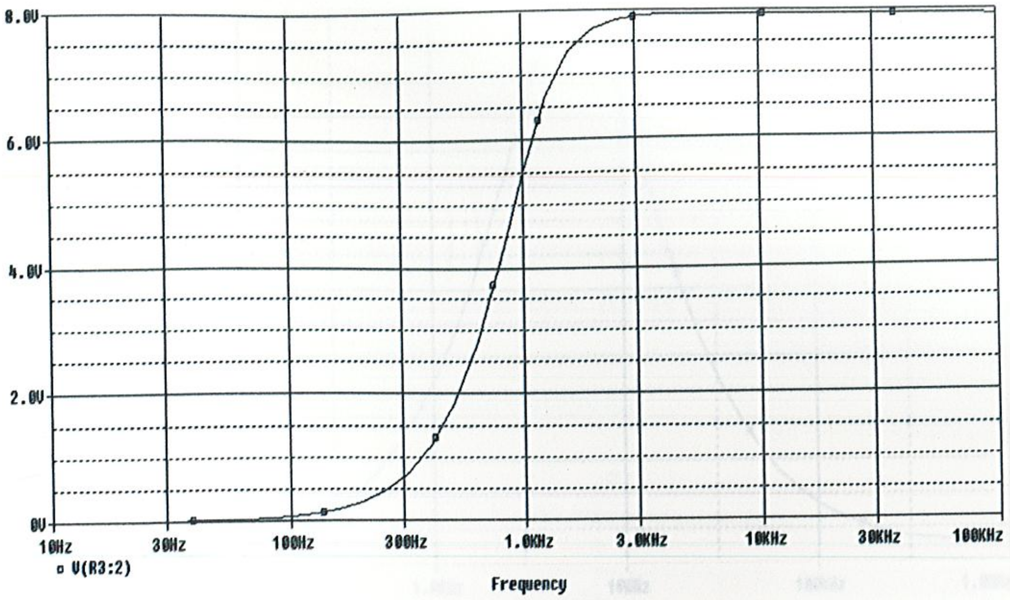
6.1.2 IMPLEMENTATION OF HPF

Second order high pass filter [(fig. 23)[8]] can be formed from a second order low pass filter simply by interchanging the frequency determining resistors and capacitors

$$f_L = \frac{1}{4\pi\sqrt{R_1 R_2 C_1 C_2}}$$



(*a*)



(*b*)

Fig. 23: Operational Amplifier second order high pass filter (*a*) circuit realization, (*b*) output waveform.

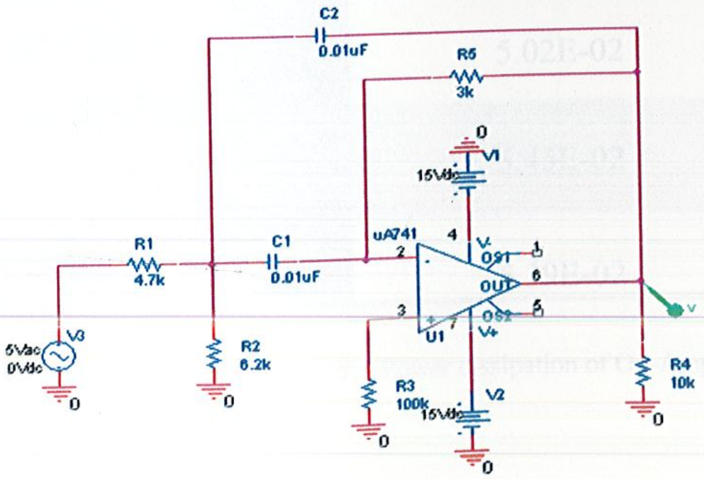
6.1.3 IMPLEMENTATION OF BPF

Narrow band pass filter [(Fig. 24) [8]] is designed for specific values of center frequency f_C and Q or f_c and BW

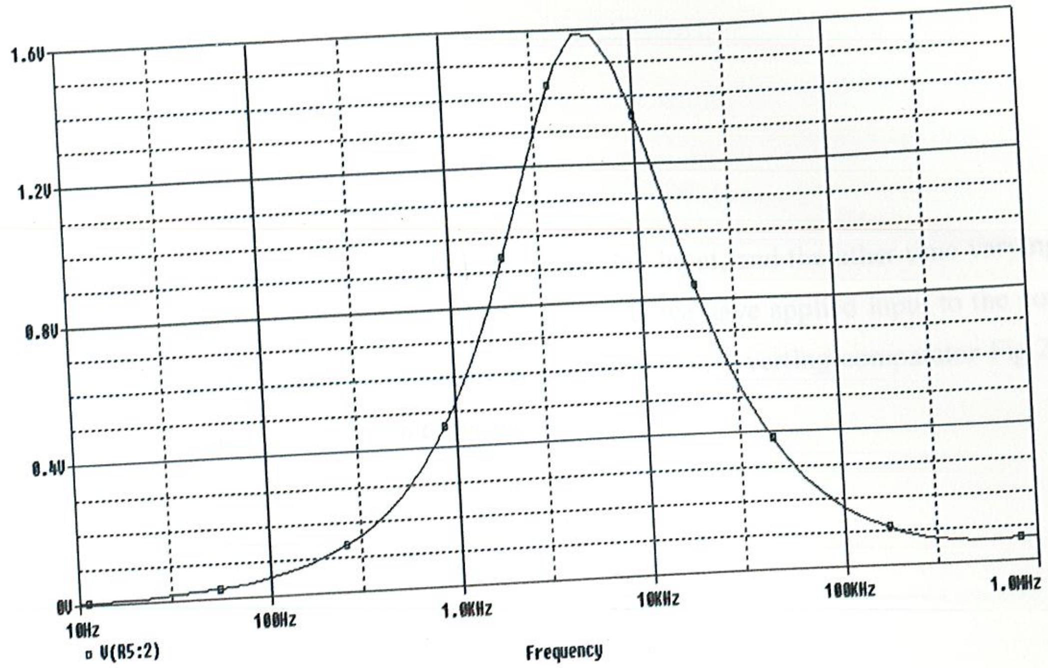
$C_1 = C_2 = C$

$A_F = R_3/R_1$

The gain A_F should satisfy $A_F < 2Q^2$



(*a*)



(*b*)

Fig. 24: Operational Amplifier second order band pass filter (*a*) circuit realization, (*b*) output waveform.

The implementation of these filters using PSpice [6] generated an output file which had the Power dissipation values as shown in Table 1.

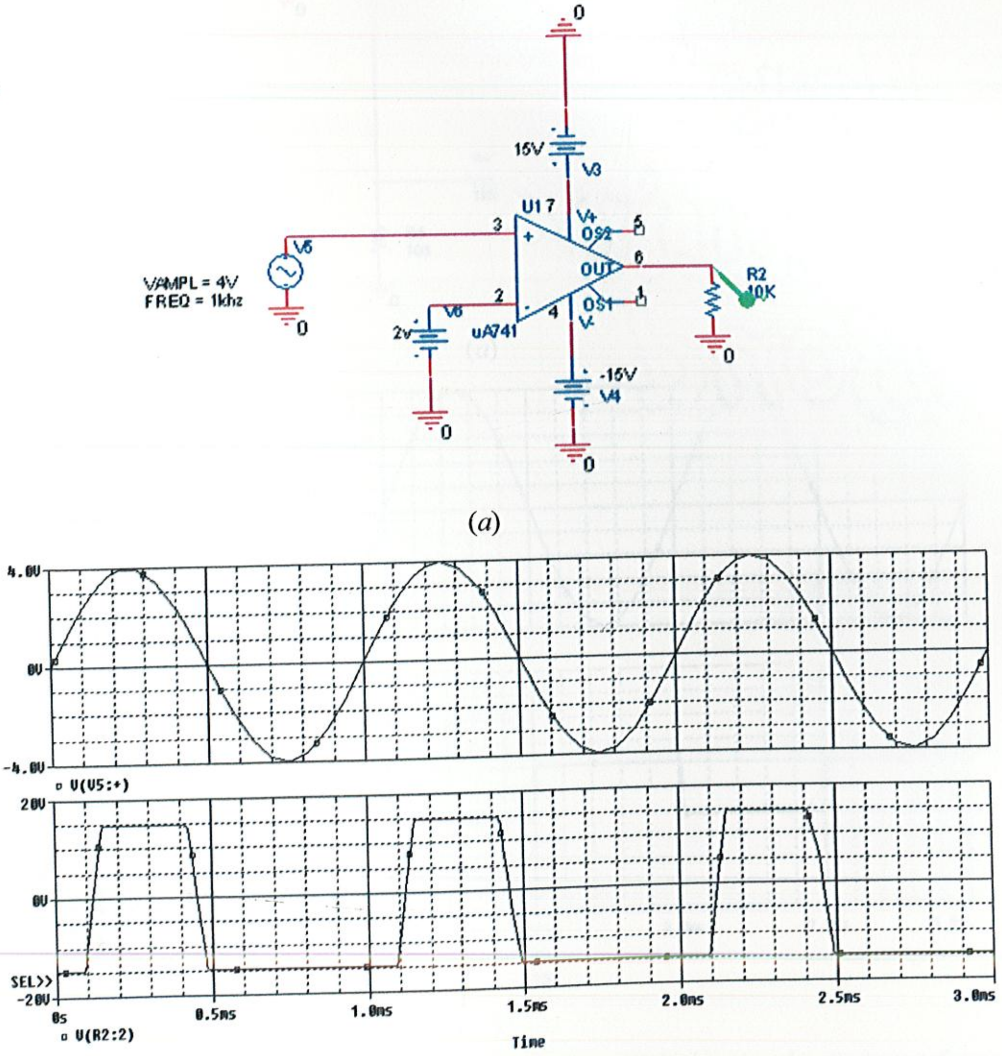
Op-Amp	Total Power Dissipation
Filter Type	WATTS
Low pass Filter	5.02E-02
High pass Filter	5.45E-02
Band pass Filter	5.39E-02

Table 1: Voltage Source Currents and Total Power dissipation of Op-Amp based filter.

6.1.4 COMPARATOR

6.1.4.1 Non-inverting comparator

A fixed reference voltage V_6 is applied to the inverting input, and the other time varying signal voltage V_5 is applied to non- inverting input. As we have applied input to the non inverting terminal of op-amp, comparator is known as non-inverting comparator Fig.25 (*a*). [8] Fig.25 (*b*) shows its input and output waveforms.



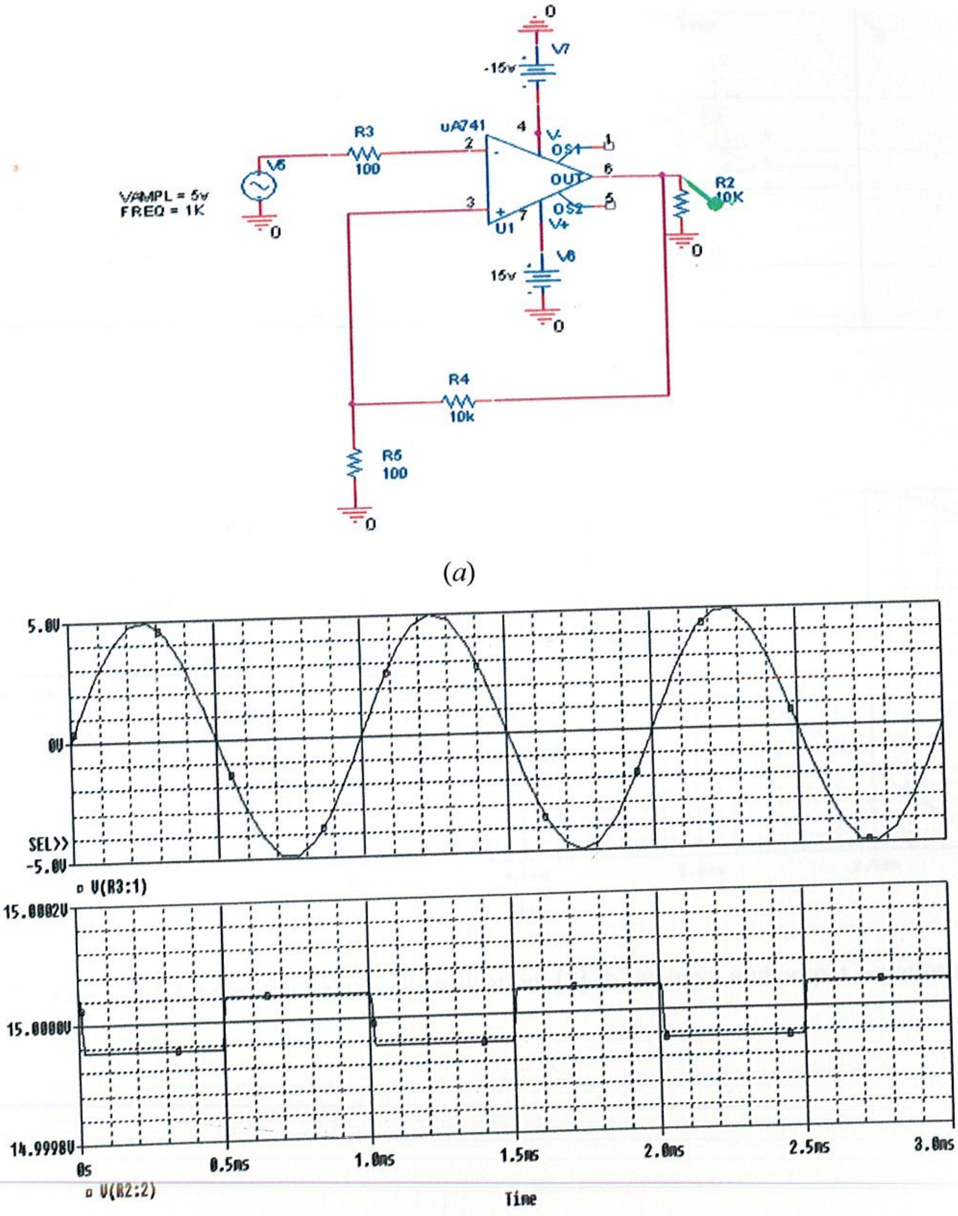
(*a*)

(*b*)

Fig. 25: Operational Amplifier (*a*) Non- inverting comparator (*b*) its input and output waveforms.

6.1.4.2 Inverting comparator

Fig.26 (*a*)[8] represents an inverting comparator in which the reference voltage is applied to non- inverting input and the other sinusoidal input waveform voltage V_5 is applied to inverting input, the output is shown in Fig.26 (*b*).

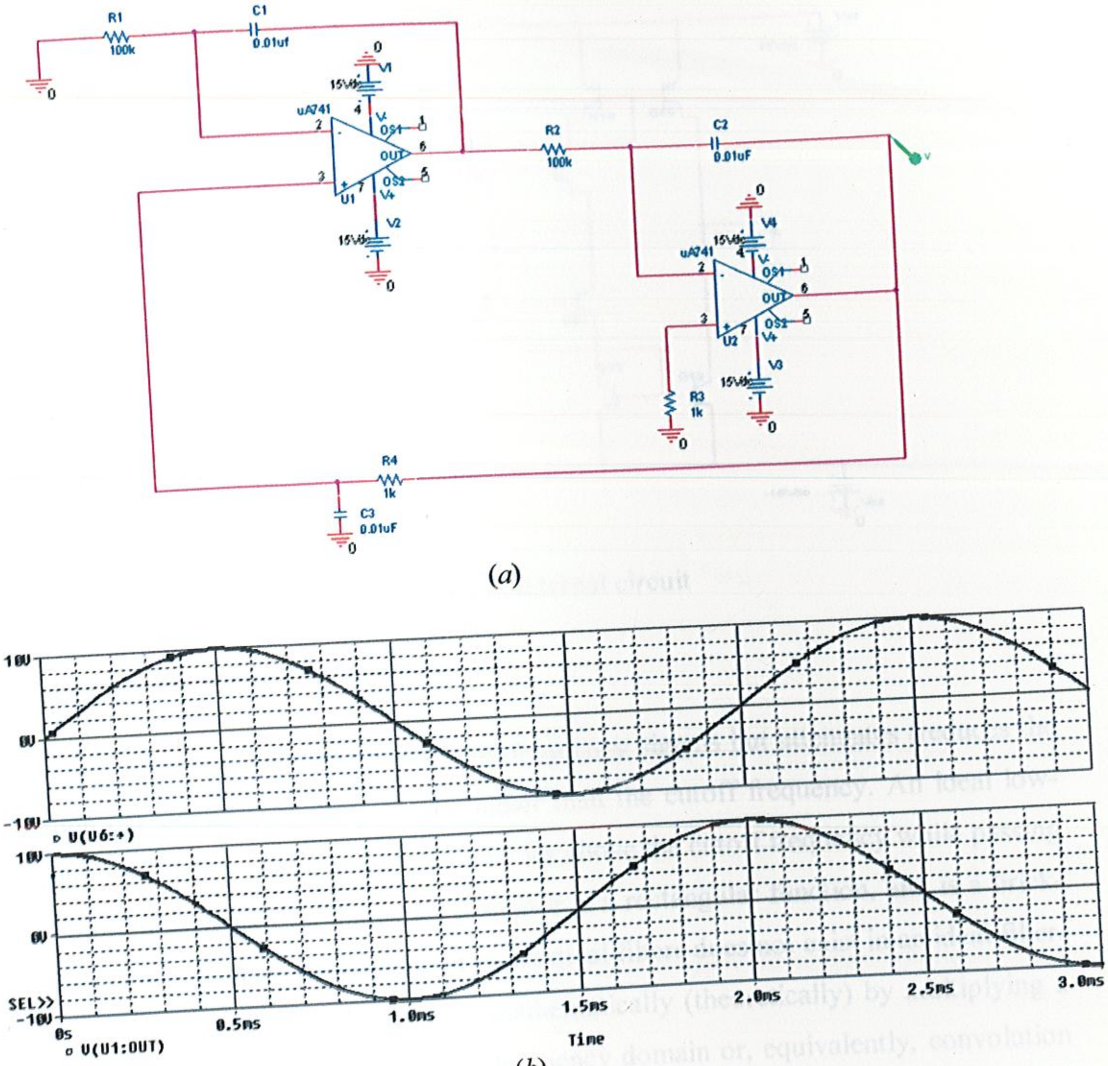


(*a*)

(*b*)

Fig. 26: Operational Amplifier (*a*) Inverting comparator, (*b*) its input and output waveforms.

6.1.5 IMPLEMENTATION OF QUADRATURE OSCILLATOR



(*a*)

(*b*)

Fig. 27: Operational Amplifier (*a*) circuit realization, [8] (b) its input and output waveforms.

6.2 CDTA: Fig 28 represents the internal circuit diagram of CDTA that we have used for realizing various circuits.

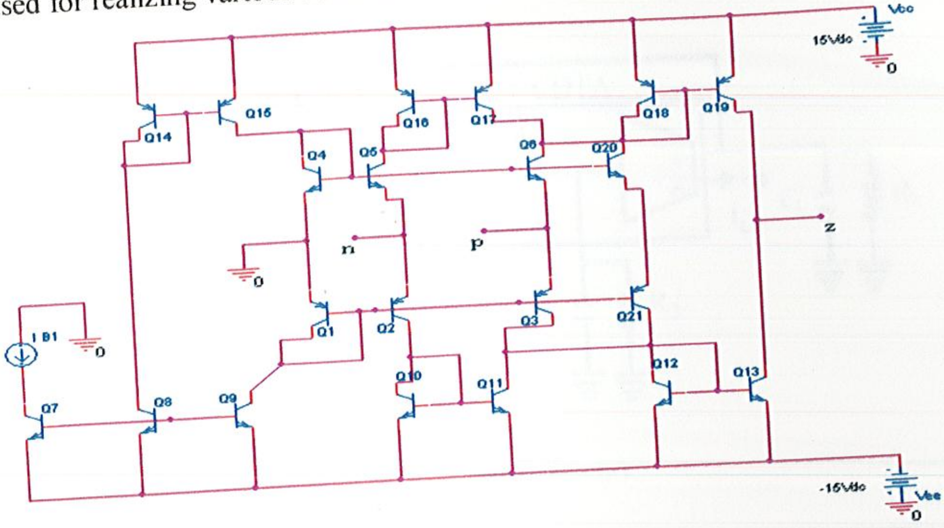
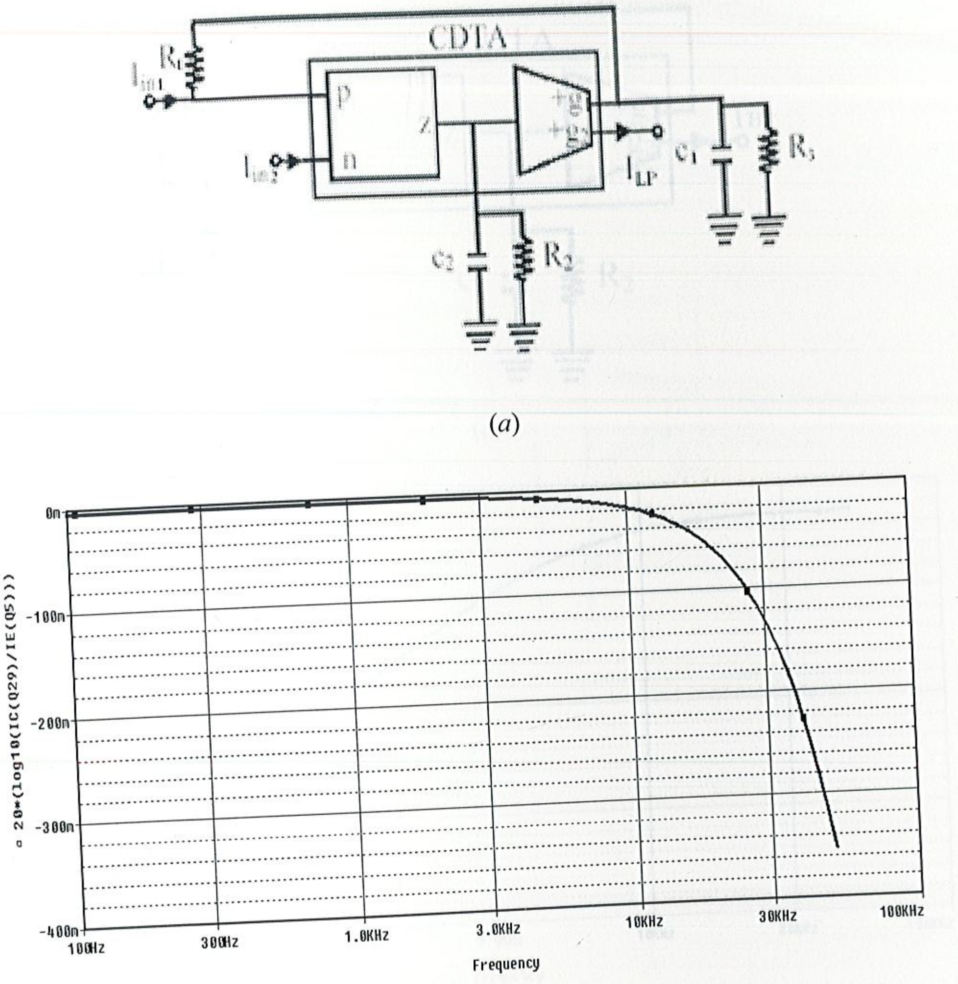


Fig. 28: CDTA Internal circuit

6.2.1 IMPLEMENTATION OF LPF

A low-pass filter is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. An ideal low-pass filter completely eliminates all frequencies above the cutoff frequency while passing those below unchanged: its frequency response is a rectangular function, and is a brick-wall filter. The transition region present in practical filters does not exist in an ideal filter. An ideal low-pass filter can be realized mathematically (theoretically) by multiplying a signal by the rectangular function in the frequency domain or, equivalently, convolution with its impulse response, a sinc function, in the time domain. The order of the filter determines the amount of additional attenuation for frequencies higher than the cutoff frequency. A first-order filter, for example, will reduce the signal amplitude by half, i.e. the power roll off approaches 20 dB per decade in the limit of high frequency. A second-order filter attenuates higher frequencies more steeply. The Bode plot for this type of filter resembles that of a first-order filter, except that it falls off more quickly. The circuit used is shown in Fig. 29(a) and it is simulated using PSpice program. The simulated result of this circuit is shown in Fig. 29(b).The designed values to obtain the response were taken as R_1=10Ω, R_2= 6KΩ, R_3=10KΩ, C_1=2μF and C_2=2μF.



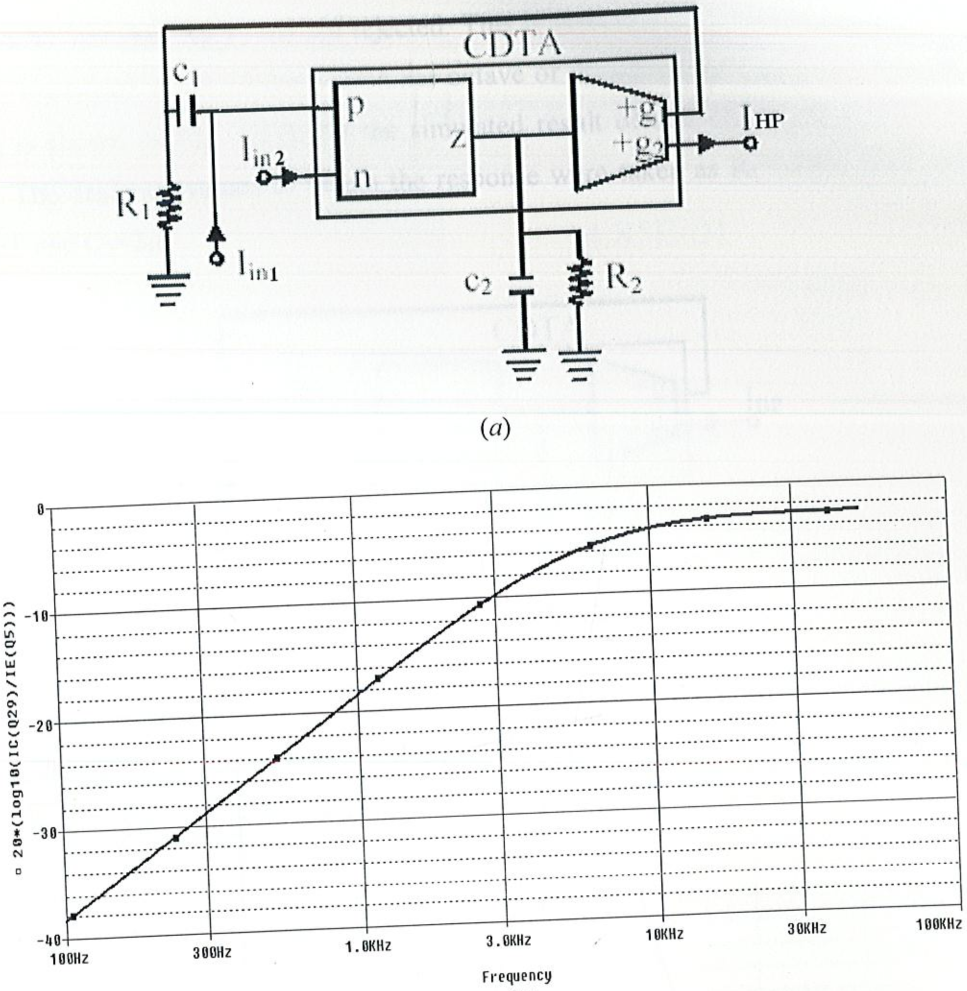
(*a*)

(*b*)

Fig. 29: (*a*) Proposed low-pass filter, (*b*) Gain response of the second order LP filter.

6.2.2 IMPLEMENTATION OF HPF

A high-pass filter is an LTI filter that passes high frequencies well but attenuates (i.e., reduces the amplitude of) frequencies lower than the cutoff frequency. The actual amount of attenuation for each frequency is a design parameter of the filter. The proposed circuit is shown in Fig. 30(*a*).The simulated result of this circuit is shown in Fig. 30(*b*).The designed values to obtain the response were taken as R_1=1kΩ, R_2= 1KΩ, C_1=2mF and C_2=2mF.



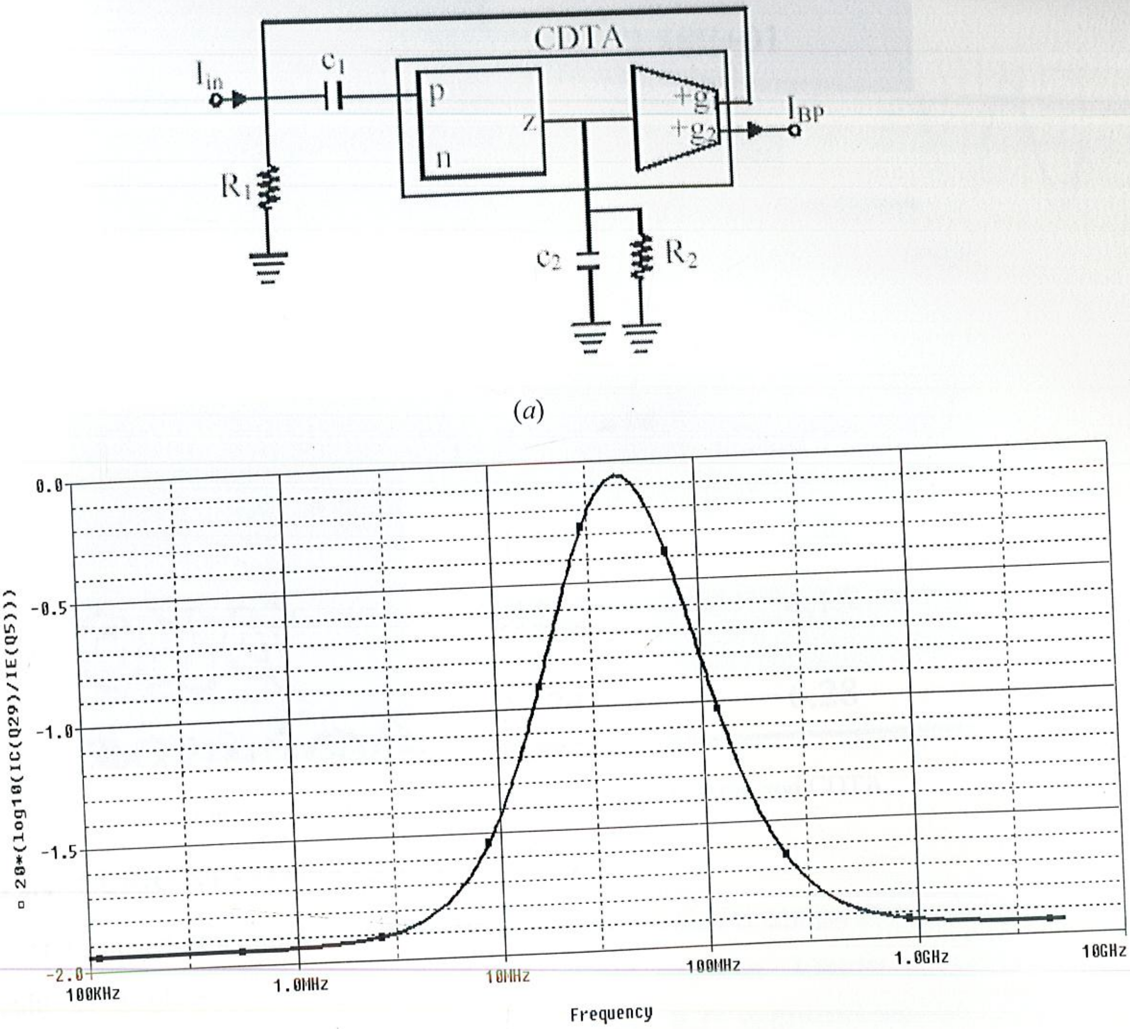
(*a*)

(*b*)

Fig. 30: (*a*) Proposed High-pass filter, (*b*) Gain response of the second order HP filter.

6.2.3 IMPLEMENTATION OF BPF

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. An ideal band pass filter would have a completely flat pass band (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the pass band. Additionally, the transition out of the pass band would be instantaneous in frequency. In practice, no band pass filter is ideal. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended pass band where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. The proposed circuit is shown in Fig. 31(*a*) and the simulated result of this circuit is shown in Fig. 31(*b*). The designed values to obtain the response were taken as R_1=100Ω, R_2= 10KΩ, C_1=2μF and C_2=2μF.



(*a*)

(*b*)

Fig. 31: (*a*) Proposed Band-pass filter, (*b*) Gain response of the second order BP filter.

When implemented in PSpice, the circuits for the second order LPF, HPF and BPF, the power dissipation values were obtained. These are shown in Table 2. Also, the voltage and current gain values for these filters, using both, op-amp as well as CDTA is shown in Table 3.

CDTA	Total Power Dissipation
Filter Type	**WATTS**
Low pass Filter	4.85E-01
High pass Filter	2.58E+01
Band pass Filter	2.89E-02

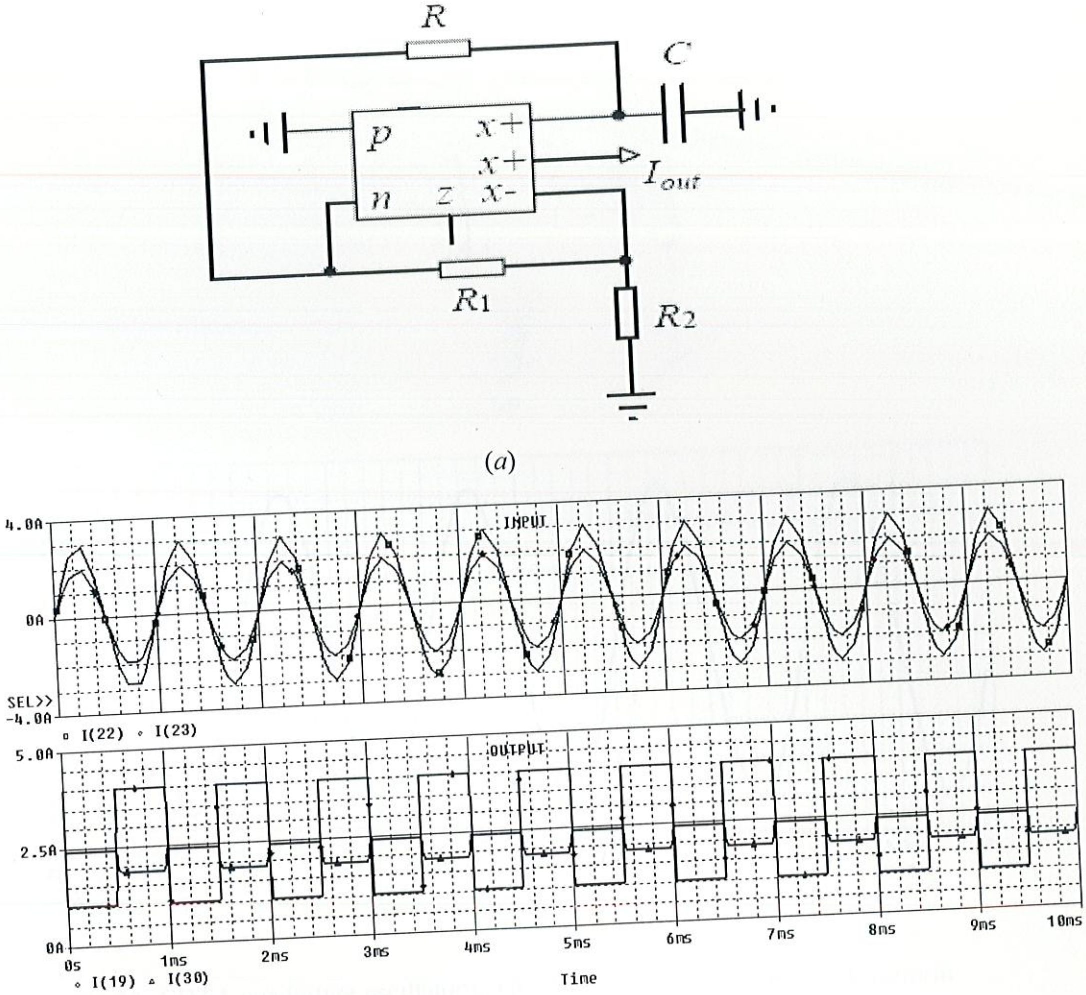
Table 2: Voltage Source Currents and Total Power dissipation of CDTA based filter.

Applications	Op-Amp	CDTA
Filters	Voltage Gain	Current Gain
Low pass Filter	1.12	3.86
High pass Filter	1.1215	4.15
Band pass Filter	2.774	6.28

Table 3: Gain of LPF, HPF and BPF using Op-Amp and CDTA.

6.2.4 CURRENT COMPARATOR

CDTA is used as a comparator because of high gain which is comparable to the voltage gain of a classical voltage-feedback operational amplifier. Current comparator is completed by a frequency dependent current divider R-C, connected into the negative feedback loop shown in Fig. 32(*a*).The output response is shown in Fig. 32(*b*).



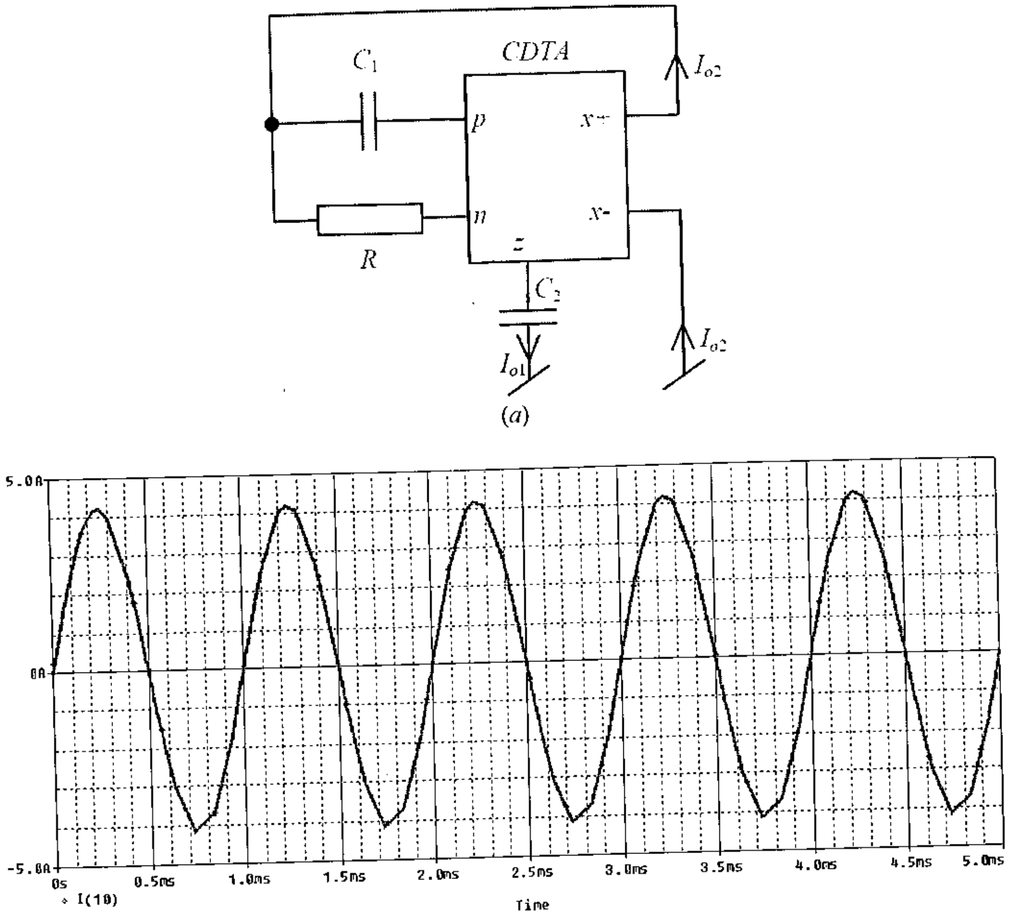
(*a*)

(*b*)

Fig.32: CDTA Current Comparator (*a*) using R = 2KΩ, C = 10pF, (*b*) output response.

6.2.5 IMPLEMENTATION OF QUADRATURE OSCILLATOR

Oscillator is an important basic building block, which is frequently employed in electrical engineering applications. Among several kinds of oscillator, the quadrature oscillator is widely used because it can offer sinusoidal signals with 90° phase difference, for example, in telecommunications for quadrature mixers and single-sideband modulators. Fig.33 shows the circuit used for realization and the output for this quadrature oscillator.

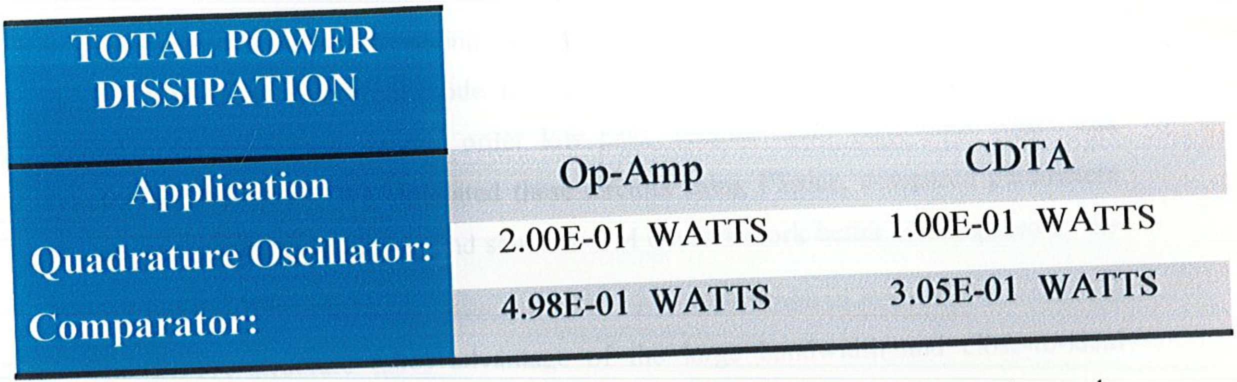


(*a*)

(*b*)

Fig.33: CDTA quadrature oscillator (*a*) Realisation circuit (*b*) Output Waveform

The power Dissipation for Quadrature Oscillator and Comparator using both, the active voltage-mode and CM devices is shown in Table 4.



TOTAL POWER DISSIPATION		
Application	Op-Amp	CDTA
Quadrature Oscillator:	2.00E-01 WATTS	1.00E-01 WATTS
Comparator:	4.98E-01 WATTS	3.05E-01 WATTS

Table 4: Total Power Dissipation of Quadrature oscillator and Comparator using Op-Amp and CDTA.

CHAPTER-7

CONCLUSION

We have used Current Differencing Transconductance Amplifier (CDTA) as the active element operating in current-mode to realize various circuits including comparator, second order high pass, second order low pass, second order band pass filters and Quadrature oscillators. We simulated these circuits using PSpice, compared parameters like power dissipation and gain and saw that CM devices work better as compared to the voltage mode ones.

The CDTA structure takes advantage of the large bandwidth and close-to-ideal terminal impedances. Its circuit is suitable for monolithic integrated circuit implementation. CDTA based circuits in this project work successfully due to the nature of the current-mode operation.

With the completion of this project and designing the various circuits, we learned not only the technical knowledge for work but also the managerial "*know how*", how to follow a project life cycle to reach the end from scratch. Our project finished successfully as the comparison between CDTA and op-amps shows how the current mode devices actually operate more efficiently than the voltage mode ones.

CHAPTER-8

FUTURE PLAN

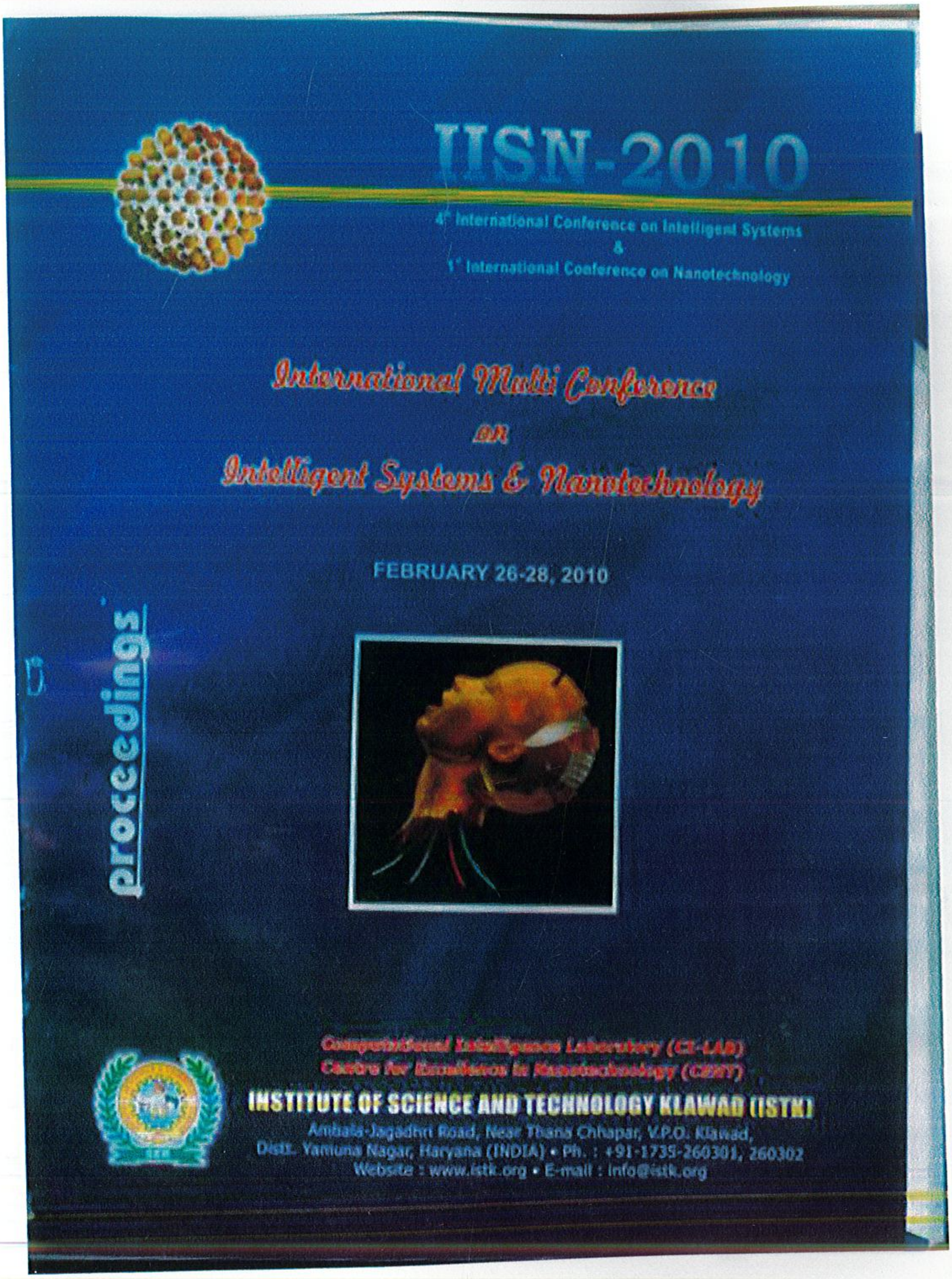
We have implemented our circuits using CDTA which has proved extremely efficient and provided better results than Op-amps. However, for certain purposes we might need the parasitic resistances at two current input ports to be controlled by an input bias current, so that it does not need a resistor in practical applications.

Therefore, the results can be further improved by employing such elements as the Current Controlled Current Differencing Transconductance Amplifiers (CCCDTA) [7].This is similar to the conventional CDTA, except that input voltages of CCCDTA are not zero and it has finite input resistances R_p and R_n at the p and n input terminals, respectively. These parasitic resistances are equal and can be controlled by the bias current.

LIST OF PUBLICATIONS

1. Shivam Rastogi, Anshika Chaudhary, Shweta Tiwari, Shruti Jain, "Current Mode Comparators Using SPICE Simulation", February 26-28, 2010, pp 36-40, 4th International Multi Conference on Intelligent Systems & Nanotechnology (IISN-2010), Institute Of Science and Technology, KLAWAD (ISTK), Ambala- Jagadhri Road, Distt. Yamuna Nagar, Haryana, India.

2. Shivam Rastogi, Shweta Tiwari, Anshika Chaudhary, Shruti Jain, "Current Mode Active Filters Using CDTA", February 26-28, 2010, pp 92-94, 4th International Multi Conference on Intelligent Systems & Nanotechnology (IISN-2010), Institute Of Science and Technology, KLAWAD (ISTK), Ambala- Jagadhri Road, Distt. Yamuna Nagar, Haryana, India.



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IISN-2010: Table of Contents

4th International Multi Conference on Intelligent Systems and Nanotechnology (IISN-2010), February 26 -28, 2010.
Institute of Science and Technology Klawad-133105, Haryana, India

Current Mode Comparators Using SPICE Simulation

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Abstract—**The non-linear way of operating the operational amplifier (op-amp) causes the device to operate primarily in saturation region and such behavior forms the basis of voltage comparator and Schmitt trigger circuits. The paper explains basic ideas how to construct and compare current-mode comparators with the utilization of Current Differencing Transconductance Amplifier (CDTA) and Current Controlled Current Differencing Transconductance Amplifier (CCCDTA) active circuit elements. These comparators enable fast comparison of input currents including a prospective hysteresis. Basic application in the area of current-mode signal generation is described. Simulation Program with Integrated Circuit Emphasis (SPICE) simulations are provided based on BJT-level.**

Keywords- **Current-mode (CM), operational amplifier, CDTA, CCCDTA.**

I. INTRODUCTION

A voltage comparator is basically a high-gain differential amplifier. The differential amplifier operates as a 'switch' in comparator circuit. A comparator can be thought of as a fast, high-gain op-amp which is not used with negative feedback. The comparator has large open-loop gain A (1). The function of a comparator is to decide which of the two inputs has larger voltage [1].

$$v_{out} = A(v_+ - v_-) = \begin{cases} +V_{max} & v_+ > v_- \\ -|V_{min}| & v_+ < v_- \end{cases} \qquad (1)$$

where V_{max} and V_{min} are approximately the power supply voltages. Therefore, the comparator converts an analog input signal into an output with two possible states. Hence, this can be thought of as a 1-bit analog to digital converter (A/D or ADC). There is more gain at high frequency, meaning faster response. Also, the amplifier can be optimized for speed at the expense of linearity. The op-amp makes an excellent voltage comparator when operating speed is not critical , Especially in view of extremely high gain (>10) of certain Op-Amp types. The op-amp should fulfill the following requirements when used as a comparator. The output must switch rapidly between saturation levels and also respond instantly to any change of conditions at its inputs. This requires wide bandwidth. High voltage gain is required to have smaller hysteresis voltage. A high common mode rejection ratio (CMRR) is required to reject the common -mode voltages, such as noise, at the input terminals of the comparator. The input offset currents and input offset voltage must be negligible, also the changes in these offsets due to temperature variant should be very slight. The output must swing between two logic levels, suitable for certain logic family such as TTL. The output transition takes place instantaneously. Such effects are more traceable at high frequencies, where the output switching time can be comparable to or even larger than the input period itself. Here we are using compensated 741 Op-Amp [2] which employs an on-chip capacitor which stabilizes the device against possible oscillation when used with negative feedback, i.e., operated in closed loop condition. In comparator applications, however, such Op-Amp is operated in the open-loop condition, so that the frequency compensation using the capacitor is not needed. In fact, the compensating capacitor is detrimental in comparator operation because it slows down the response unnecessarily.

In the last decade, there has been much effort to reduce the supply voltage of electronic circuits. This is due to the command for portable and battery- powered equipment. Since a low-voltage operating circuit becomes necessary, the current mode technique is ideally suited for this purpose more than the voltage-mode one. Consequently, there is a growing interest in synthesizing the current-mode circuits because of their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and low power consumption [3], [4].

A 5-terminals active element, Current Differencing Transconductance Amplifier (CDTA), seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters. It is current-mode element whose input and output signals are currents. The active circuit component CDTA (Current Differencing Transconductance Amplifier) is particularly useful for the current-mode applications, because its input and output signals are currents [5], [6], [7]. CDTA consists of the input current-differencing unit and of multiple-output OTA (Operational Transconductance Amplifier). Because of high current gain of the CDTA which is comparable to voltage gain of a classical voltage-feedback operational amplifier, the CDTA can be used as a current comparator. The required hysteresis can be accomplished by applying a proper positive feedback. However, the CDTA can not be controlled the parasitic resistances at two current input ports so when it is used in a circuit, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area. Modified-version CDTA, which is newly named Current Controlled Current Differencing Transconductance

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Current-mode Active Filters Using CDTA

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***Abstract*—In this paper, new current-mode (CM) second-order filters {Low Pass Filter (LPF), High Pass Filter (HPF), Band Pass Filter (BPF)} employing a single recently introduced active device Current Differencing Transconductance Amplifier (CDTA). The circuit introduces bare minimum number of active and passive components. The circuit also employs cascadibility feature. Simulation Program with Integrated Circuit Emphasis (SPICE) simulations are provided based on BJT-level.**

***Keywords*- Current differencing transconductance amplifier, Current-mode active filters.**

I. INTRODUCTION

At present there is a growing interest in the design and development of CM active filters to perform a number of analog signal processing tasks. This is attributed to their wider bandwidth, simpler architecture, wider dynamic range, and higher frequency operations as compared to their voltage-mode counterparts. The contemporary active elements such as operational Transconductance Amplifier (OTA)[1], second generation current conveyor, current feedback amplifier, four terminal floating null or etc are used to realize different filtering functions. These active devices have either high input impedance and high output impedance or high input impedance and low output impedance. The requirement for CM circuits is low input (ideally zero) and high output (ideally infinite). Accordingly, the recently introduced active device namely CDTA, having low input and high output impedances is highly desirable active device for the implementation of signal processing in current mode. This element consists of a unity-gain current source controlled by the difference of the input currents and a multi-output transconductance amplifier providing electronic tenability through its transconductance gain. The use of CDTA as active component simplifies the implementation thereby providing the circuits with lesser number of passive components vis-à-vis its counterparts leading to compact structures in some applications. Some realizations using CDTA as active element operating in current-mode have been developed. Active filters used in this paper, employ CDTA in addition to resistors and capacitors. The type of element used dictates the operating frequency range of the filter. Although active filters are most extensively used in the field of communications and signal processing, they are employed in one form or another in almost all sophisticated electronic systems. Radio, television, telephone, radar, space satellites and biomedical equipment are but a few systems that employ active filters. In this paper, second order low-pass, high-pass and band-pass filters have been presented by using single CDTA.

II. THEORY

A. Basic concept of CDTA

The CDTA element [2, 3] has a couple of low-impedance input terminals p and n. The difference of currents Ip and In flows out of the z terminal into an outside load, causing the voltage drop which is transferred to current Ix via the internal transconductance gm [4].When the z terminal is not loaded, the voltage across this terminal is given by its high internal resistance. The product of this impedance and the transconductance gm represents the current gain of the CDTA. Value of current Ix is limited by internal current source Ic, which is a part of the transconductance stage. When the product of the difference input current Ip-In and the current gain is beyond the interval <-Ic, Ic>, the current Ix will be clipped, analogous to the output voltage limitation of the operational amplifier in the saturation regime. CDTA can be thought as a combination of a current differencing unit followed by a dual-output operational transconductance amplifier, DO-OTA. Ideally, the OTA is assumed as an ideal voltage-controlled current source and can be described by Ix = gm.(V+ – V–), where Ix is output current, V+ and V– denote non-inverting and inverting input voltage of the OTA, respectively. Note that gm is a function of the bias current. When this element is used in CDTA, one of its input terminals is grounded (e.g., V– = 0V). With dual output availability, Ix + = – Ix – condition is assumed.

B. Circuit analysis

The schematic symbol of the CDTA is shown in Fig. 1 (a). The inputs p and n produce difference current which is transferred to the z terminal is converted into a set of output currents by a dual output transconductance stage. The port relationships are given by the following set of equations represented by (1).

$$V_p = V_n = 0,$$

$$I_z = I_p = -I_n,$$

$$I_{x+} = g_m.V_z,$$

$$I_{x-} = -g_m.V_z.$$

where $V_{z-} = I_z.Z_z$ and

Z_z is the external impedance connected to z terminal of the CDTA
ZZ is the external impedance connected to z terminal, Vp,

BIBLIOGRAPHY

1. A.U Keskin and D. Biolek, Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA) IEE Proc.-Circuits Devices Syst., Vol. 153, No. 3, June 2006.
2. C.Toumazao, F.J. Lidgey, and D.G. Haigh, Analogue IC design: the current – mode approach. London: Peter Peregrinus, 1990.
3. D. Biolek, CDTA Building block for current- Mode analog signal processing," Proceedings of the European conference on circuit theory and design 2003 - ECCTD'03, 2003, Krakow, Poland, pp. 397400.
4. Dalibor Biolek, Viera Biolková, Current-Mode CDTA-Based Comparators: Dept. of Microelectronics / Radioelectronics, FEEC, Brno University of Technology, Czech Republic, grants No. 102/04/0442 and 102/05/0277.
5. D.R. Bhaskar, V.K. Sharma , M. Monis and S.M.I. Rizvi, " New current-mode universal biquad filter "Microelectronics Journal, Vol. 30, No.9,pp. 837-839,1999.
6. M. H. Rashid, "*Introduction to PSpice Using OrCAD for Circuits and Electronics*", *Prentice-Hall Inc., 3rd edition 2003.*
7. Montree Siripruchyanun and Winai Jaikla, Realization of Current Controlled Current Differencing Transconductance Amplifier (CCCDTA) and Its Applications: Manuscript received on July 26, 2006; revised on October 10, 2006.
8. Ramakant A. Gayakward, *"Op-Amps and Linear Integrated Circuits", fourth edition, Pearson Education.*